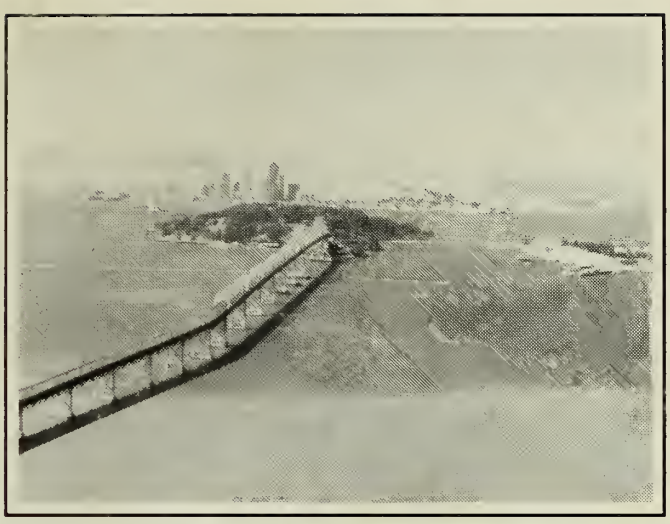

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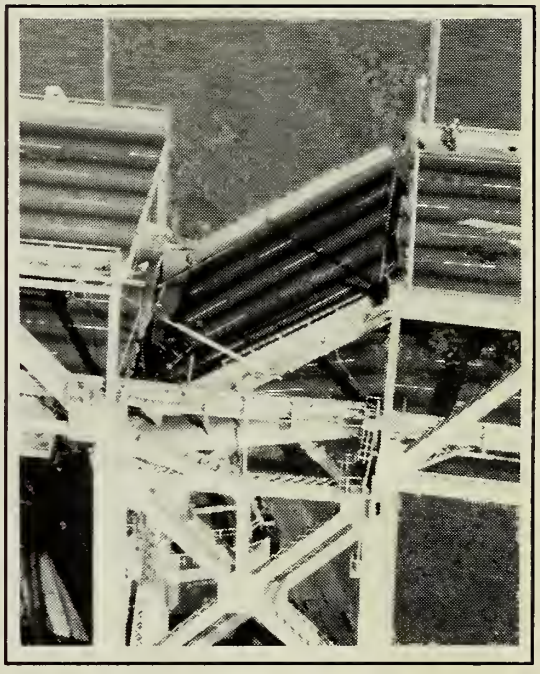
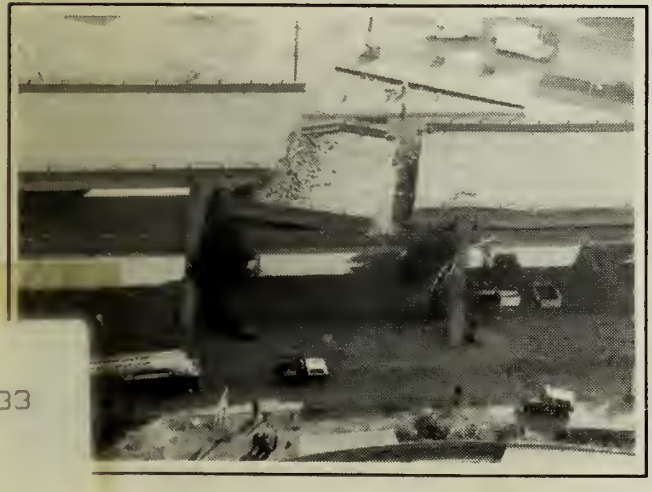
Department of California Highway Patrol



1989 Loma Prieta Earthquake Summary Report



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REFERENCE BOOK

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Commissioner's Messsage

Dear California Residents,

On October 17, 1989, a long awaited, yet unexpected, earthquake struck the heart of the San Francisco Bay Area. The Loma Prieta Earthquake, as it has been designated, was centered in the Santa Cruz Mountains with a magnitude of 7.1 on the Richter Scale. The earthquake caused substantial damage to numerous buildings, structures and unfortunate loss of life.

It became the responsibility of the California Highway Patrol to investigate and document two of the more visible results of the Loma Prieta Earthquake: the collapse of the I-880, Cypress Street Viaduct, and the failure of two 50-foot spans of the San Francisco-Oakland Bay Bridge. The documentation of these reports comprises over 2000 pages of text, charts, graphs and diagrams detailing the circumstances surrounding these tragedies. The intent of this summary is to provide to the general public an overview of the results of our Department's investigation.

This summary cannot hope to address the entire scope of personal tragedy and the stories of perseverance and heroics so evident on October 17, 1989, and the days that followed. It will take you through these events, summarize the statements that people made recalling their memories, analyze the physical evidence and provide you with our best recreation of the circumstances surrounding the failure of these two structures.

On behalf of the California Highway Patrol, I wish to thank all of the allied agencies, emergency service providers, and those private citizens who worked so diligently and cooperatively with the CHP in the performance of our unique tasks during the post-earthquake recovery. The assistance with data collection and photographic documentation was also very important to the CHP for the reconstruction of the collapse of these two structures. This summary also contains information provided to the CHP from other agencies.

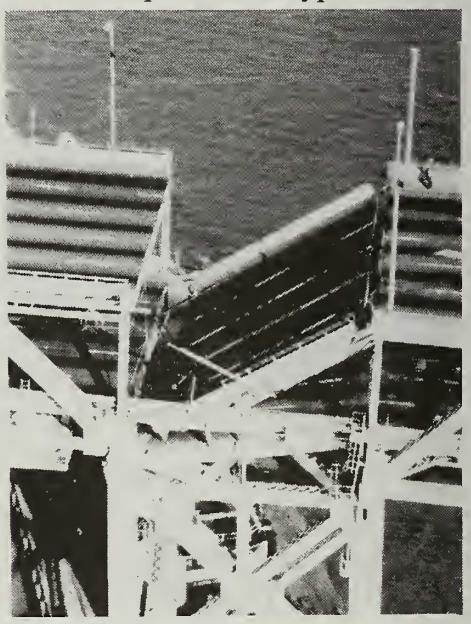
The specially formed Golden Gate Division Multidisciplinary Accident Investigation Team has spent seven months collecting and evaluating the data used to reconstruct the events surrounding the collapse of the Cypress Street Viaduct and the failure of the San Francisco-Oakland Bay Bridge. I believe the results prove the value of their efforts; the final report is complete, accurate, and without political bias. This summary very briefly consolidates the major objectives of the full report into something more easily read by the lay person. I hope the findings will ultimately provide for a safer transportation system and a more comprehensive understanding of these two tragedies.

M. J. Hannigan, Commissioner

I-80 San Francisco-Oakland Bay Bridge and the I-880 Nimitz Freeway Collapse Summary

Statement of Purpose

At the direction of M. J. Hannigan, Commissioner of the California Highway Patrol, a special investigation team was established to document the earthquake induced collapse of two 50 foot spans of the I-80, San Francisco-Oakland Bay Bridge (SFOBB) and the collapse of the Cypress Street Viaduct of I-880, the Nimitz Freeway.

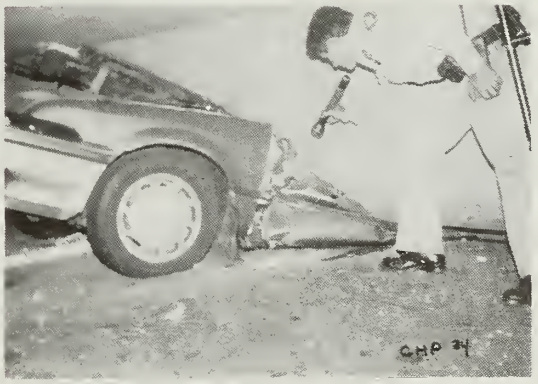


This special investigation team, which became known as the Golden Gate Division Multidisciplinary Accident Investigation Team (MAIT), was officially formed on October 26, 1989, and began operation on October 30, 1989, to investigate the SFOBB and the Cypress Street Viaduct failures. Members for this team were specially selected for their area of expertise as it related to this project.

The purpose of this publication is to summarize the investigation reports about the collapse of the SFOBB closure span and the I-880 Nimitz Freeway. It accurately summarizes the sequence of events taking place just prior to and during these collapses. This summary is not intended to replace either report in any way. It is designed primarily for parties with a casual interest or individuals interested in gaining a cursory knowledge of the circumstances surrounding these events.

The complete results of the investigations may be obtained by parties of interest by requesting the complete "I-80 San Francisco-Oakland Bay Bridge Structure Collapse Report" and the "I-880 Nimitz Freeway (Cypress Viaduct) Structure Collapse Report" from the San Francisco Area Office and the Oakland Area Office of the CHP, respectively.

contents



Introduction

On October 14, 1989, the National League champion San Francisco Giants met the American League champion Oakland A's for the first game of the 1989 World Series in Oakland. The Oakland A's won the first two games played in Oakland and on October 17, 1989, the series traveled to Candlestick Park for the third game of the championship series. At about 5 p.m., most Bay Area residents were either attending in person or tuned their televison sets to the imminent start of the third game of the World Series.

But at 5:04 p.m. on October 17, 1989, a far more dramatic scenario than man could ever devise was played out. Solid ground moved like a wave through the footings of the Cypress Street Viaduct and the San Francisco-Oakland Bay Bridge. The Loma Prieta Earthquake, registering 7.1 on the Richter scale, caused two 50 foot sections of the Bay Bridge to fall from their supports and a portion of the Cypress Street Viaduct, slightly over three-quarters of a mile long, to collapse.

Unbelievably, no deaths were directly attributable to the Bay Bridge failure. Only four vehicles sustained damage, three persons were severely injured, five were moderately injured and four complained of pain. A traffic accident that happened fully 30 minutes after the tremor accounted for the only fatality.

Tragically, but even more miraculously, on the .76 mile stretch of collapsed freeway at peak commute hour traffic, only forty-two people lost their lives and 108 persons suffered injury, three of whom were on surface streets adjacent to the structure. Immediately after the quake, the media quoted sources reporting 250 to 300 deaths in the Cypress Structure rubble. Considering that the 12th Street overcrossing of I-880 has a "peak daily travel rate" of 15,000 vehicles per hour, normal traffic conditions would place 161 vehicles on I-880. At an occupancy rate of 1.5 - 2 persons per car, their estmate should have been accurate. But on this day, because of the Bay Area World Series, only 107 vehicles were on the upper and lower levels of this portion of the Nimitz Freeway as it wrenched and twisted, and finally collapsed.

As the final report is being finished, seven months later, the rubble from the Cypress Street Viaduct has been cleared and the Bay Bridge has long since been repaired. Perhaps the report and this summary will help to prevent us from forgetting the enormity of this tragedy.

The day was October 17, 1989, the weather was clear and warm. At approximately 1704 hours, an earthquake later named "Loma Prieta", measuring 7.1 on the Richter scale, struck the Santa Cruz area causing extensive damage to the greater San Francisco Bay Area and Santa Cruz Area communities.

Two fifty foot long, five lane wide sections of the double decked San Francisco-Oakland Bay Bridge fell and .76 miles of the double decked Cypress Street Viaduct partially collapsed as a result of the earthquake.

Meteorological Data

The National Weather Service reported weather observations taken from the San Francisco Airport on October 17, 1989. The following observations at 1750 hours were recorded:

Temperature:	73 degrees
Dew Point:	45 degrees
Wind:	13 knots from the N/W
Ceiling:	none
Visibility:	8 miles
Barometer Pressure:	29.97 (millibars)

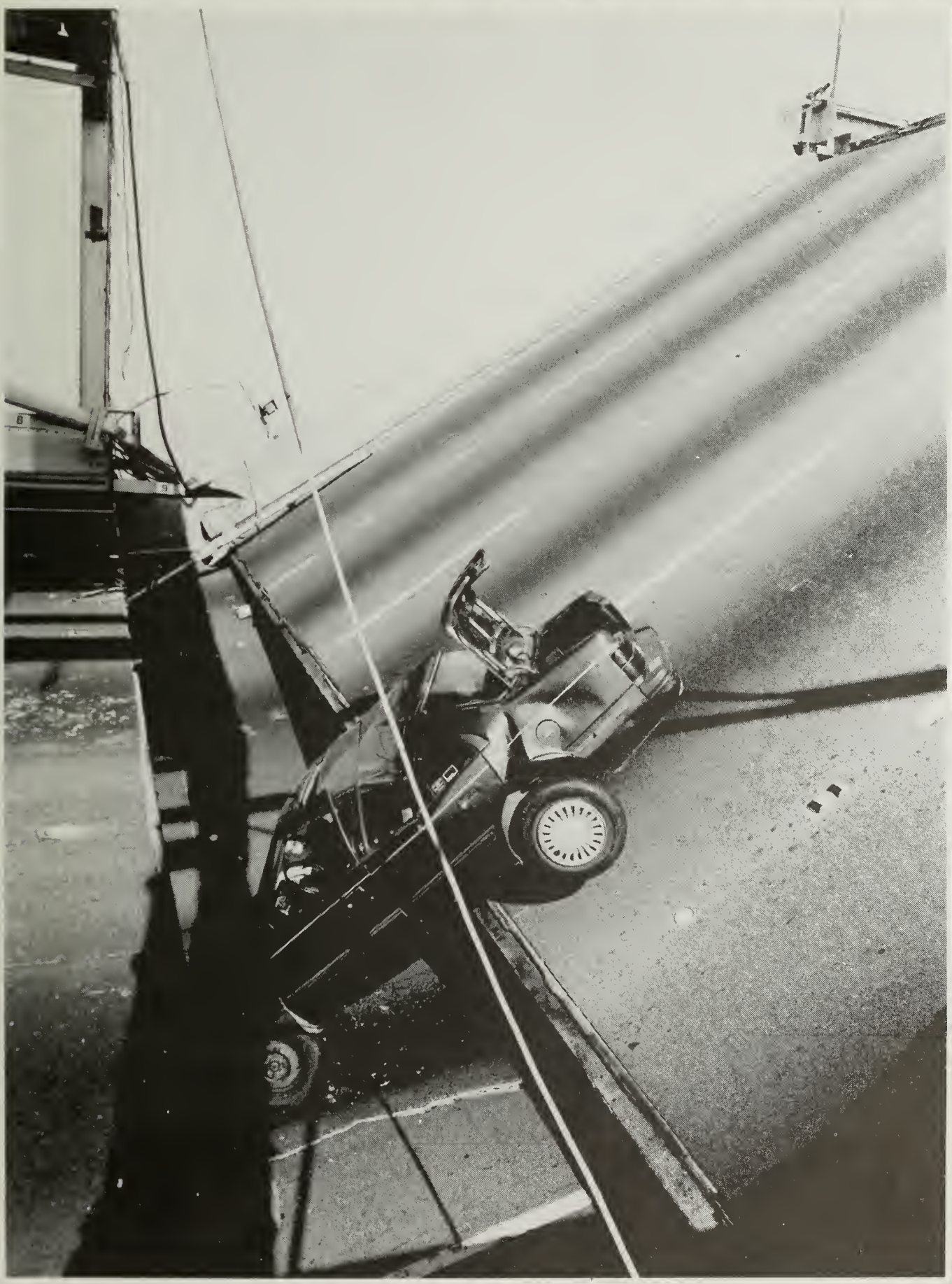
The traffic control tower at the Oakland Airport was contacted to provide weather information for October 17, 1989, recorded at 1745 hours:

Temperature:	79 degrees
Dew Point:	53 degrees
Wind:	11 knots from the N/W
Ceiling:	none
Visibility:	10 miles
Barometer pressure:	29.97 (millibars)

Seismic Data

The earthquake was located along the San Andreas fault in the Santa Cruz Mountains. The earthquake was felt as far away as Reno and Las Vegas, Nevada and Los Angeles, California. It was the largest magnitude earthquake centered in northern California since 1906.

The epicenter of this earthquake was located approximately 10 miles northeast of the city of Santa Cruz and approximately 20.5 miles south of San Jose, near a 3791 foot Peak named Loma Prieta. The SFOBB and the Cypress Street Viaduct are located approximately 62 miles north of this epicenter.



The small circle locates the area of the failed spans of the San Francisco-Oakland Bay Bridge

Scene Identification I-80

Interstate 80 is an east-west freeway which crosses the United States from the George Washington Bridge in Richfield Park, New Jersey, to the US 101 interchange in San Francisco. In the San Francisco Bay Area, this facility provides access between the East Bay communities and the city of San Francisco, via the San Francisco-Oakland Bay Bridge. This portion of I-80 is located between Yerba Buena Island and the city of Oakland, at Post Mile 0.29 in Alameda County.

The portion of I-80 covered in this investigation is located on the Bay Bridge at Tower E-9, in what is commonly called the cantilever section of the bridge. At this location, I-80 is a bi-level roadway with westbound traffic running above eastbound traffic. The upper and lower decks of the Bay Bridge collapsed at Tower E-9.

This location is approximately 100 lineal feet west of a 2000 foot radius, curved section of the bridge, and runs generally southwest to northeast.

Structure Description

The San Francisco-Oakland Bay Bridge is approximately 4.44 miles long and crosses the east and west bay via Yerba Buena Island. Proceeding eastward from the San Francisco Anchorage at Beale Street to the west side of Yerba Buena Island (the west bay crossing), the structure is basically a 10,300 foot long cable suspension bridge. Across Yerba Buena Island the structure consists of a reinforced concrete viaduct and tunnel. There are a series of connecting ramps which provide access to and from the island.

Proceeding eastward from Yerba Buena Island to the city of Oakland (the east bay crossing), the structure's basic configuration includes three truss types. First is a 2,421 foot long cantilever truss, followed by five through trusses each measuring approximately 500 feet in length. These are followed by fourteen deck trusses, each measuring approximately 290 feet in length. The only sections of the east bay crossing that are not of truss design are the two 50 foot closure spans which cross Tower E-9.

Tower E-9 is the main anchor tower for the through trusses to the west and the deck trusses to the east. These trusses are rigidly attached to each side of the tower, which provides an anchorage to resist longitudinal movement in the bridge. The roadways meeting at the trusses are connected by closure spans.

Roadway General Description

The San Francisco-Oakland Bay Bridge is a ten lane, double-deck freeway with five lanes of travel each for eastbound and westbound traffic. The roadway was field measured and found to have 11.5 foot wide travel lanes bordered by raised metal walkways and barrier railing.

Speed Limit

The speed limit for I-80 for each direction of travel at this location was posted at 50 MPH.

Traffic Volumes

The Annual Average Daily Traffic Volume on the Bay Bridge at the San Francisco/Alameda County Line is 240,000 vehicles per day. The peak hourly volume is 21,600 vehicles per hour.

Pre-Earthquake

On October 17, 1989, the afternoon commute traffic was lighter than usual for the Bay Area. This was directly attributable to the third game of the World Series scheduled for 5:30 p.m. at Candlestick Park. A large number of people were already at the stadium and an equally large number of people left work early to participate in pre-game activities or to watch the game on television.

The weather was nearly perfect with temperatures in the mid 70's and a mild wind blowing from the northwest.

The average speed for eastbound traffic was approximately 48 mph and approximately 54 mph for westbound traffic. The spacing between vehicles was normal for these speeds.

At Earthquake

On October 17, 1989, at 1704 hours, the 1989 Loma Prieta Earthquake struck. For many motorists, their first indication of the earthquake came when the radio stations went off of the air. This was immediately followed by light, moderate, or violent shaking of their vehicles, depending on where they were in the Greater Bay Area. This was also the case for motorists on the SFOBB.

Drivers on Yerba Buena Island (YBI), especially those in the YBI tunnel when the earthquake stuck, felt no movement of their vehicles associated with the earthquake. Their only indication that something was wrong came when the tunnel lights went out and the radio stations they were listening to went off the air.

When the earthquake struck, the drivers who were on the suspension section of the bridge felt a side to side, lateral movement of their vehicles.

The most violent motion on the bridge was reported by those motorists who were on the truss section, closest to the E-9 tower, where the closure spans are located. These motorists reported feeling a violent up and down, as well as a side to side, motion just prior to the failure of the closure spans.

A large majority of these drivers thought they were experiencing a tire or mechanical failure. They braked their vehicles to a stop, or reduced their speed to between 10 to 30 mph, and then continued driving in their original directions of travel. The uniformity of these driver's response to their vehicle motion is reflected by the fact that there were very few vehicle-to-vehicle or vehicle-to-bridge impacts associated with the earthquake induced motion of the vehicles.

Post-Earthquake

Immediately following the earthquake and the collapse of the upper and lower deck closure spans at tower E-9, traffic approaching the collapse from both the eastbound and westbound directions came to a stop. Traffic at other locations on the bridge that slowed or came to a stop during the earthquake continued to drive in their original directions of travel. As they approached the collapse, they became stopped in gridlocked traffic. This traffic rapidly backed up from the collapse to the west on the lower deck and to the east on the upper deck.

Because of the short distance from the collapse to the Toll Plaza, the westbound traffic gridlocked on the Oakland side of the collapse was cleared from the bridge within 30 minutes following the earthquake.

As a consequence of actions taken by people on the bridge and the configuration of the bridge itself, eastbound traffic was effectively divided into three distinct groups as follows:

Group 1. Traffic on the SFOBB located from approximately center anchorage back to the west into San Francisco.

Group 2. Traffic on the SFOBB from center anchorage eastward to just east of the Yerba Buena Island tunnel.

Group 3. All traffic from just east of the Yerba Buena Island tunnel eastward to the collapse.

Group 1 traffic was routed off of the on-ramps at, or near, the west anchorage of the SFOBB. The traffic that was near center anchorage was eventually turned around and directed westbound on the lower deck back toward San Francisco.

Group 2 traffic, and some of the western-most group 3 traffic were routed off the SFOBB at YBI and then redirected from the Island back to the upper deck of the SFOBB, with the intention that they proceed westbound on the upper deck back to San Francisco. Initially, this was being accomplished by a Caltrans bridge tow truck operator, a private security officer working for the U.S. Navy at Treasure Island, and several citizen volunteers.

Later in the evening, the traffic control for group 2 traffic was accomplished as a cooperative effort between naval personnel, law enforcement and citizen volunteers. As far as can be determined from those people interviewed in this investigation, there was no organized traffic direction on the upper deck at Yerba Buena Island prior to the fatal traffic collision involving the driver of a 1980 Mercury Zephyr.

After the majority of group 1 and 2 traffic was cleared, group 3 traffic was turned around and routed westbound on the lower deck back to San Francisco.

In each of these groups of traffic, there were motorists who abandoned their vehicles and walked, or were given a ride, off the bridge. After traffic was cleared, these abandoned vehicles were towed by Caltrans and various tow companies from the bridge to Treasure Island or to a storage lot at 8th and Brannan Streets in San Francisco.

Data Analysis

From an analysis of the statements of the 160 persons interviewed during this investigation, the following conclusions were drawn:

Traffic Flow

- The traffic flow on the SFOBB, eastbound, was light in comparison to the normal traffic flow for that day of the week and that hour of the day.

- The traffic flow on the SFOBB, westbound on the suspension section, was also lighter than usual. Westbound on the truss section, the traffic flow was described as medium.

Speed of Travel

- The average speed for westbound traffic on the SFOBB, for all spans, was approximately 54 mph.

- The average speed for eastbound traffic on the SFOBB, on the truss section, was approximately 49 mph.

- The average speed for eastbound traffic on the SFOBB, on the suspension section, was approximately 43 mph.

- The average speed for traffic on the Yerba Buena Island section, both directions, was approximately 51 mph.

Reaction to the Earthquake - Truss Section

- The majority of the drivers on the truss section reacted to their vehicle motion by decelerating as if they had a flat tire and brought their vehicles to a stop.

Reaction to the Earthquake - Suspension Section

- The majority of the drivers on the suspension section reacted to their vehicle motion by decelerating and bringing their vehicle to a stop.

Reaction to the Earthquake - Yerba Buena Island Section

- The vast majority of the drivers on the YBI Section did not experience any vehicle motion as a consequence of ground motion associated with the earthquake. The majority of these people experienced their first indication that an earthquake had occurred when the radio station they were listening to went off the air and/or the lights in the YBI tunnel went out.

Lateral Motion of Vehicles - Truss Section

- Forty-three of the 73 persons (58.9 %) who were on the truss section indicated that they experienced lateral motion. Over 88 percent of those on the truss section, who responded to this question, stated they felt a strong side-to-side motion during the earthquake.

Lateral Motion of Vehicles - Suspension Section

- Thirty-three of the 61 persons (54.1 %) who were on the suspension section indicated that they experienced lateral motion. Over 72 percent of those on the suspension section, who responded to this question, stated they felt a strong side-to-side motion during the earthquake.

Vertical Motion of Vehicles - Truss Section

- Sixteen of the 73 persons (21.9 %) who were on the truss section indicated that they experienced vertical motion during the earthquake.

Vertical Motion of Vehicles - Suspension Section

- Fourteen of the 61 persons (23 %) who were on the suspension section indicated that they experienced vertical motion during the earthquake.

Order of Motion of Vehicles - Truss Section

- The majority of those persons on the truss section, who felt more than one type of vehicle motion when the earthquake struck, felt the lateral movement first. Those that felt vertical movement first were very close to tower E-9 and witnessed the collapse of the closure span.

Order of Motion of Vehicles - Suspension Section

- Nearly 66 percent of the persons on the suspension section responding to this area of questioning indicated that they felt the lateral motion first.

Structure Motion - Truss Section

- Of the 73 persons on the truss section who were interviewed, there were only 15 responses (20.5%) concerning the motion of the structure. Of these, 46.7 percent indicated a lateral motion of the structure and 53.3 percent indicated a vertical motion. Those describing the most violent motion were those individuals closest to tower E-9 and the closure span.

Structure Motion - Suspension Section

- Of the 61 persons on the suspension section who were interviewed, there were only 14 responses (23 %) concerning the lateral motion of the structure and eight responses (13.1 %) regarding the vertical motion of the structure. Regarding the lateral motion of the suspension section, the majority responding to this area of questioning indicated that the bridge was swaying side to side. Regarding the vertical motion of the suspension section, the majority of those responding described the vertical motion as being like a "wave".

Time of Structure Motion - Closure Span Failure

- Based on a complex evaluation of driver response to earthquake induced vehicle motion, it is estimated that the truss section of the SFOBB experienced strong motion over a time span of approximately 8 to 12 seconds. The failure of the upper and lower decks of the closure span, at tower E-9, occurred very near the end of this time span.

- The strong motion on the suspension section most probably occurred over a time span similar to the estimated duration time for strong structural motion on the truss section.

- The motion on the Yerba Buena Island section of the SFOBB was not felt by drivers who were on this section when the earthquake struck. Consequently no assessment of the motion of the structure or its duration could be made.

Data Analysis

Fatalities, Injuries, and Vehicle Damage

- This investigation identified 5 vehicles, with a total of 20 people, that were directly, or indirectly, involved in the collapse of the SFOBB closure spans. There were 3 vehicles, with 16 people, eastbound on the lower deck, and there was 1 vehicle, with 2 people, westbound on the upper deck, when the earthquake struck and the closure spans collapsed.

  Approximately 30 minutes after the earthquake, there was 1 vehicle, with 2 people, travelling eastbound on the westbound upper deck. This vehicle drove into the gap created by the fallen upper deck closure span.

Number of People Killed, Injured and Uninjured

- There was only 1 person killed and 13 people injured as a direct, or indirect, result of the closure span failures. There were 6 people who were uninjured.

Severity of Injury
All Injured Parties

- Of the 13 people injured, 5 suffered severe injury, 4 suffered other visible injury, and 4 people complained of pain.

Severity of Injury
Eastbound Parties

- Of the 11 injuries suffered by eastbound motorists, 4 were severe, 3 were visible injury, and 4 were classified as complaint of pain.

Severity of Injury
Westbound Parties

- Of the 2 injuries suffered by westbound motorists, 1 was a severe injury and the other was a visible injury.

Severity of Damage to Vehicles
All Involved Vehicles

- Of the 20 vehicles directly, or indirectly, involved in the closure span failures, 4 sustained total damage and 1 sustained minor damage.

Severity of Damage to Vehicles
Eastbound Vehicles

- Of the 4 vehicles that were travelling eastbound on the bridge, 3 sustained total damage and 1 sustained minor damage.

Severity of Damage to Vehicles
Westbound Vehicles

- There was only 1 involved vehicle travelling westbound on the upper deck of the bridge. This vehicle sustained total damage.

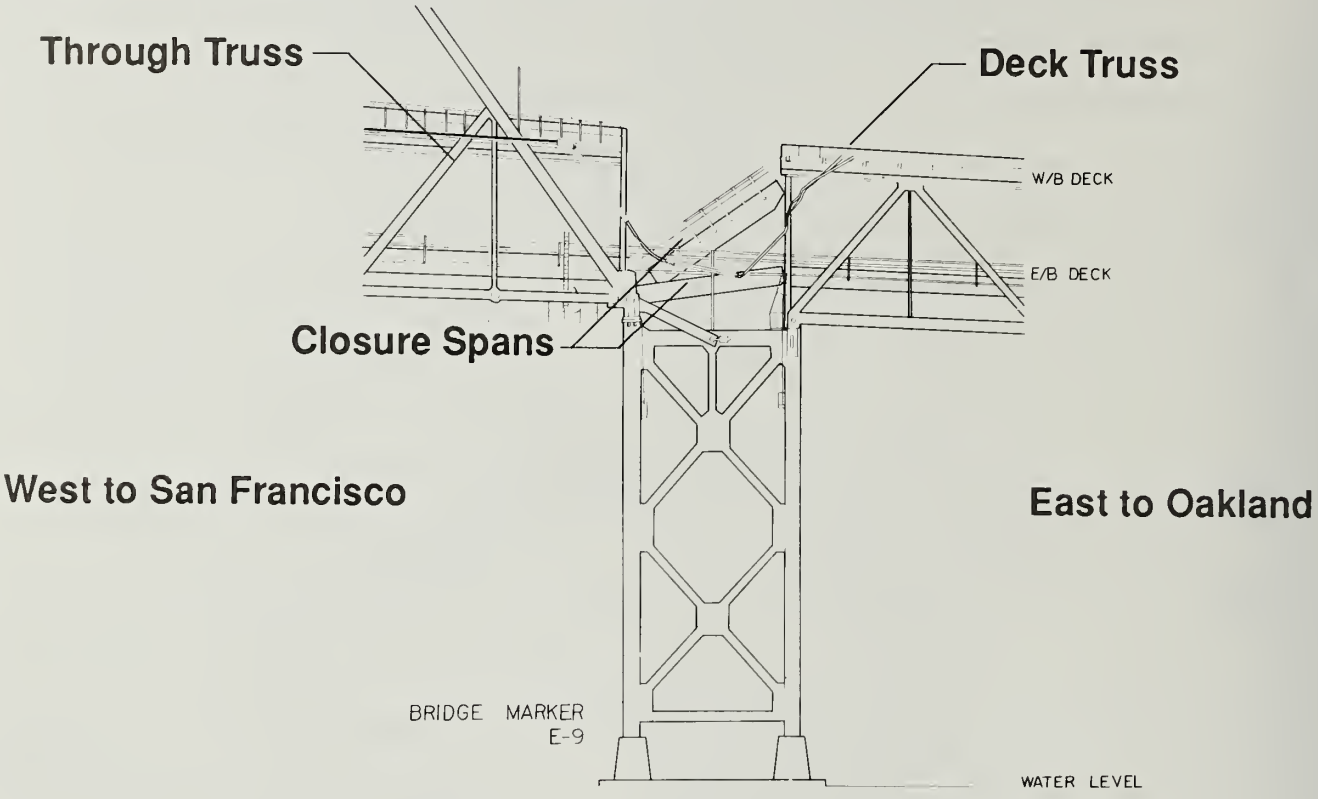
I-80 SAN FRANCISCO - OAKLAND BAY BRIDGE Structure Collapse - Summary Sheet

Westbound Direction of Travel		Eastbound Direction of Travel	
Occupant Summary		**Occupant Summary**	
Total Number of Involved Parties:	2	Total Number of Involved Parties:	18
Total Number of Fatalities:	0	Total Number of Fatalities:	1
Total Number of Injuries:	2	Total Number of Injuries:	11
Number with Complaint of Pain:	0	Number with Complaint of Pain:	4
Number with Visible Injury:	1	Number with Visible Injury:	3
Number with Severe Injury:	1	Number with Severe Injury:	4
Total Number Uninjured:	0	Total Number Uninjured:	6
Vehicle Summary		**Vehicle Summary**	
Total Number of Involved Vehicles:	1	Total Number of Involved Vehicles:	4
Number with Total Damage:	1	Number with Total Damage:	3
Number with Major Damage:	0	Number with Major Damage:	0
Number with Moderate Damage:	0	Number with Moderate Damage:	0
Number with Minor Damage:	0	Number with Minor Damage:	1
Witness Summary		**Witness Summary**	
Total Number of Witnesses Contacted:	12	Total Number of Witnesses Contacted:	132

Total Summary

Occupant Summary		Vehicle Summary	
Total Number of Involved Parties:	20	Total Number of Involved Vehicles:	5
Total Number of Fatalities:	1	Number with Total Damage:	4
Total Number of Injuries:	13	Number with Major Damage:	0
Number with Complaint of Pain:	4	Number with Moderate Damage:	0
Number with Visible Injury:	4	Number with Minor Damage:	1
Number with Severe Injury:	5	**Witness Summary**	
Total Number Uninjured:	6	Total Number of Witnesses Contacted:	144

Tower E-9



I-80 San Francisco-Oakland Bay Bridge structure collapse

Failure Scenario

The earthquake induced horizontal and vertical forces in the trusses of the East Bay crossing. These forces caused the bolts connecting the deck truss sections to the east side of the E-9 tower to fail and permitted free movement across this support point.

An inspection indicated a minimum of ten inches of movement occurred with sufficient force to cause deformation of the roadway expansion assembly to the immediate east of the tower. This movement resulted in a final, at rest, displacement of the deck truss of 5-1/2 inches to the east, and 1 inch to the north. The two 50 foot closure spans over tower E-9 were rigidly attached to the deck truss to the east and were free moving on 6 inch bearing seats which were attached to the through truss to the west. As the trusses on the east side of the tower began to move, the closure spans moved off their bearing seats on the west side and fell.

The inspection indicates that both closure spans fell at, or about, the same time, with the upper span impacting the lower span after it came to rest. When the closure spans dropped, they remained connected to the east deck truss and hinged downward, exposing the east supporting transverse floor beams. The final resting position of the partially collapsed upper roadway span created an eastward rising ramp leading directly to the face of the exposed transverse beam.

Vehicle Scenarios

During the investigation, individual scenarios were prepared for each of the drivers, passengers, witnesses and vehicles directly involved in the events of the earthquake. Of these summaries, four driver scenarios were selected to provide the reader with a sense of what happened and how it was addressed.

A 33 year-old male driving a 1984 gray Mazda 626 and his passenger, **a 41 year-old female** were westbound in the number 2 traffic lane of the SFOBB at approximately 45 mph. They were approaching a Caltrans bridge tow-truck driver's location. The tow-truck driver was stopped in the westbound number 1 lane approximately 100 feet east of the E-9 tower. The driver was providing service to an out-of-gas motorist, stopped in front of him in the number 1 lane.

The driver of the Mazda was adjacent to the tow truck when his vehicle began to bounce up and down. He initially thought he had a flat tire and began pumping his brakes to slow down and stop. As he decelerated, westbound on the upper deck, he managed to keep his vehicle in the number 2 traffic lane and moved onto the upper deck closure span at tower E-9 of the SFOBB.

As the upper deck began to fall, the Mazda was on the deck, near its west end, and nearly at a stop. The driver and his passenger saw the upper deck separate, felt a falling sensation, and knew they were falling towards the lower deck and the bay below them.

The west end of the lower deck, below them, had also fallen and its north edge became stuck against part of a metal structure located immediately underneath the lower deck. This prevented the lower deck from falling any farther. The west end of the upper deck, with the Mazda on it, fell downward and struck the lower deck. The Mazda nosed downward onto the lower deck, pitched forward around its front end and its roof struck the east edge of exposed roadbed to the west of the fallen closure span. The Mazda then rocked backward and came to rest at the west edge of the gap created by the collapse of the upper and lower deck closure spans. The center of its right side was supported by the west edge of the collapsed upper deck and its front end rested against the collapsed lower deck.

After his car came to rest in the gap, the driver climbed out of the driver's side window and over the hood of his vehicle to the west edge of the deck. He then climbed up to the lower deck roadway to the west of the collapsed spans. He told his passenger to get out of the vehicle. She got out the same way he did and was helped to the lower deck, west of the collapsed spans, by the driver and a U.S. Marine who was a passenger on an A.C. Transit bus that stopped 10 feet east of the E-9 tower on the lower, eastbound deck.

Both the driver of the Mazda and his passenger walked westbound on the lower deck to Treasure Island where they were eventually transported by ambulance to San Francisco General Hospital in San Francisco for treatment. The driver suffered visible injuries consisting of a laceration to his tongue, soft tissue injury and complained of pain. His female passenger suffered severe injury consisting of a lacerated knee, soft tissue injury, and fractures of the sternum and lower spine. The Mazda sustained total damage and was subsequently removed from the bridge by a Caltrans tow truck.

A 39 year-old male was on his way home riding his Honda motorcycle eastbound on the SFOBB at approximately 75 mph. He was several hundred feet west of tower E-9 just before the earthquake struck.

The rider felt his motorcycle start to sway and he began to slow down. As he tried to slow down, he couldn't maintain

control. The motorcycle went down and slid to a stop approximately 50 yards west of the now collapsed upper and lower deck closure spans at tower E-9.

The motorcycle rider looked up and saw that the bridge had collapsed approximately 50 yards ahead of him. He picked up his motorcycle and started riding westbound on the eastbound lower deck back to San Francisco. On his way back to San Francisco, he warned as many drivers as he could that the bridge had collapsed.

The rider of the motorcycle suffered minor injury, consisting of complaint of pain to his shoulders. His motorcycle sustained minor damage in the form of dents and scrapes to its left side.

A 35 year-old male was also eastbound on the bridge in the number 4 traffic lane at approximately 45 mph, and was west of tower E-9. He was driving a 1986 Dodge commuter van carrying 12 passengers on their way home from work.

The driver felt his van start to shake back and forth and began to brake. He saw a truck ahead of him in the right lane swerve into the right side rail of the bridge, so he continued to slow down and moved from the number 4 traffic lane into the number 3 lane.

At a relatively slow speed, he drove onto the lower deck closure span at tower E-9. As he was crossing the west end of the closure span, two of his 12 passengers could see the west edge of the closure span pulling away from the east, exposing the bay below.

When the Dodge commuter van was completely on the lower closure span, the west edge of the span pulled away from its bearing seats and began to fall toward the bay. The driver stated, "We were suddenly going up, like a drawbridge." He attempted to accelerate off the lower deck. As the Dodge van was moving toward the east, up the fallen lower deck, the bottom of the upper deck struck the right rear of the roof of his van. The Dodge van continued eastbound and launched over the ramp created by the fallen lower deck. The Dodge van landed on the platform deck to the east of the closure span.

The driver brought the van safely to a stop to the east of the collapse closure spans and got out to see what had happened. He saw the fallen spans behind him and the damaged right rear of his van.

Several of his passengers had been injured, so he got back in the van and drove eastbound. He stopped at the Toll Plaza to get medical attention for his injured passengers, but found that there were no medical facilities of any kind there.

Two of his more seriously injured passengers were transported from the Toll Plaza to Kaiser Permanente Hospital in Oakland by another motorist. The driver was able to drive back to his home using surface streets. On his way, he managed to drop off his remaining passengers near their homes.

The Van sustained major damage as a consequence of being struck by the upper deck and when landing on the lower deck after being airborne.

A 27 year-old male, driving a red, 1988, Pontiac Lemans, and his fiance, **a 32 year-old female**, were eastbound on the SFOBB on their way back to Walnut Creek. They were just west of tower E-9 when the earthquake struck .

When the earthquake struck, the Pontiac Lemans began to move from side to side and the driver began to slow down. When he was just a few car lengths from the west end of the closure spans, the upper deck fell, striking the lower deck directly in front of his vehicle. The driver attempted to bring the Lemans to a stop and, at a very slow speed, nosed over the east end of the roadway into the gap created by the fallen closure spans.

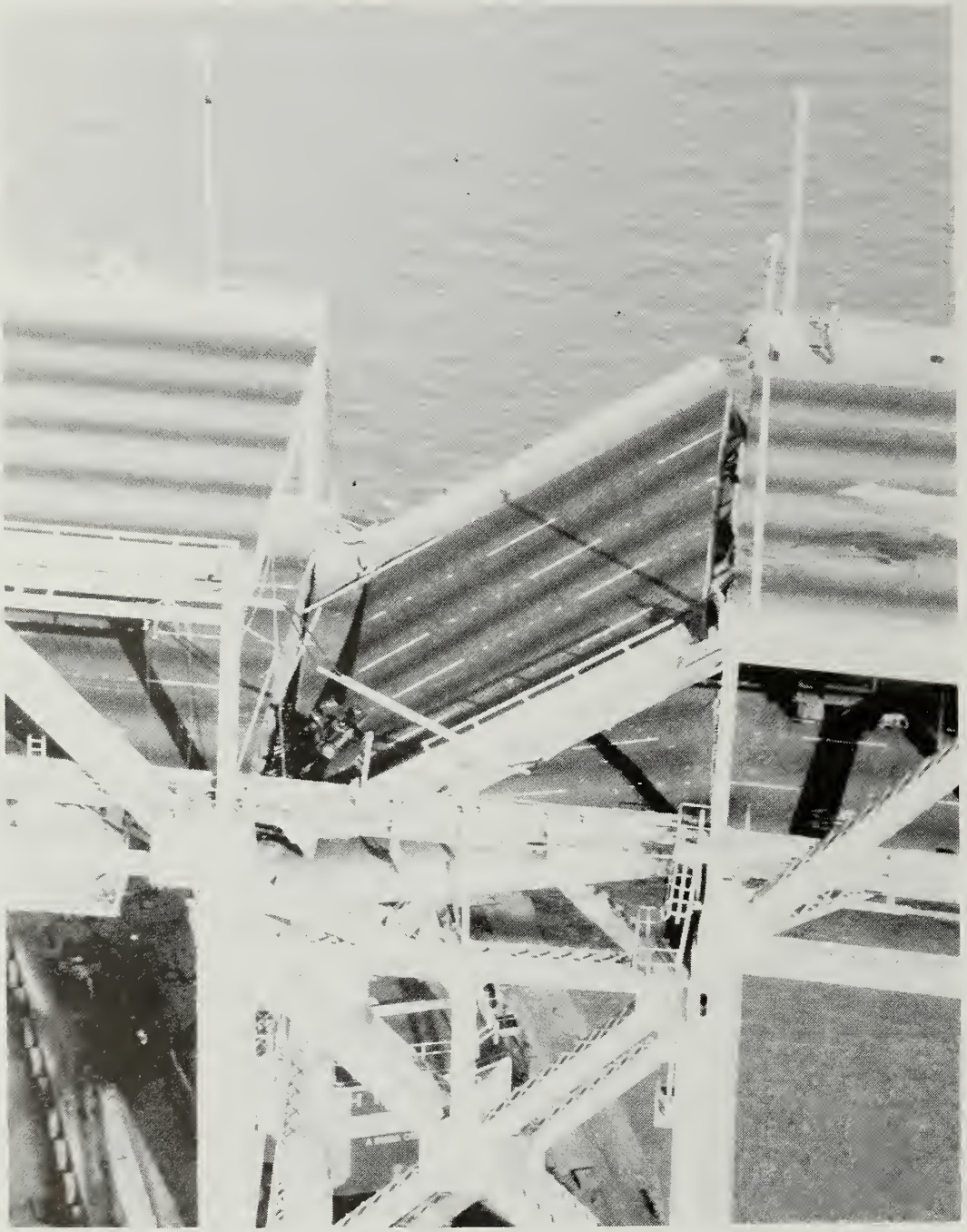
The Pontiac Lemans came to rest with its rear wheels in the eastbound number 3 traffic lane and its front end overhanging the west end of the span

with its front bumper in contact with the collapsed upper deck, partially in the gap created by the collapsed closure spans.

The driver and his finance climbed out of the Lemans and up onto the lower deck to the west. They eventually walked back toward Yerba Buena Island and got a ride on an AC Transit Bus to Hayward.

Neither the driver nor his passenger was injured. Their vehicle sustained total damage, partially as a consequence of the fall and partially as a consequence of extrication from the bridge.

The Bay Bridge Fatality



During the response of emergency personnel, lengthened by gridlocked traffic and thousands of persons out of their vehicles, a vehicle driven the wrong way (eastbound on the westbound top deck) ran off the upper deck and into the gap that had been created by the collapse of the fifty foot closure spans at tower E-9. The vehicle struck the east end of the collapsed westbound deck.

As a result, the 23-year-old female driver sustained fatal injuries. Her brother, who sustained major injuries, was the only other person in the vehicle.

This investigation was conducted by the Central Division Multidisciplinary Accident Investigation Team (MAIT). For parties of interest, additional details concerning the incident involving the driver and her passenger may be obtained by contacting the San Francisco Area Office of the California Highway Patrol.

Classification

While the death of the driver and the injury of her passenger are being reported as earthquake related, the incident meets the definition of a motor vehicle traffic accident. Consequently, this incident, while being documented in this report, was also investigated by the California Highway Patrol as a motor vehicle traffic collision following established departmental policy and procedures.

Collision Scenario

The driver of the 1980 Mercury Zephyr had picked up her brother from the San Francisco International Airport and was on the SFOBB, eastbound near the west end of the suspension section, when the earthquake struck.

It is not known exactly what her reaction to the earthquake might have been.

After the earthquake, according to information provided by her brother, the driver became gridlocked in traffic to the east of theYerba Buena Island Tunnel.

Approximately 20 to 30 minutes after the earthquake struck, at the instruction of a Caltrans tow-truck operator, she turned her vehicle around and drove onto Yerba Buena Island. They were directed by a male in a blue uniform and another citizen to go to the upper deck of the bridge. When they got to the upper deck of the bridge, they saw people going both eastbound and westbound.

The passenger stated that his sister, confused at this point, turned east towards Oakland. The driver began driving eastbound in the westbound lanes of I-80.

She encountered at least one vehicle which was also traveling eastbound in the westbound lanes of the upper deck. One vehicle was ahead of her, proceeding eastbound in the westbound number 1 traffic lane at approximately 20 mph. She overtook and passed this vehicle using the westbound number 2 traffic lane. After completing the passing maneuver, she pulled back into the westbound number 1 traffic lane and, just seconds later, drove into the gap created by the collapse of the upper deck closure span at the E-9 tower.

There was no indication that she applied the brakes prior to going into the gap. Velocity calculations indicate that she drove her vehicle off the end of the pavement at an estimated velocity of 49 mph. The Mercury went airborne, flew approximately 40 feet, and struck the east edge of the fallen upper deck.

On impact, the Mercury slid up the deck and its front end became lodged on the hinge formed by the exposed east end of the upper deck closure span. Both the driver and passenger were left in their car until it could be towed out of the gap and onto the upper deck to the east of the gap.

They were extricated from the Mercury and flown via Coast Guard helicopter to Letterman General Hospital in San Francisco. The driver was pronounced dead on arrival at the hospital.

Mechanism of Injury

Driver

The driver of the Mercury suffered fatal internal injuries as a consequence of the impact.

The damage to the interior of the vehicle on the driver's side indicated contact with the steering wheel and lower dash area. The steering column and wheel were forced upward. This is consistent with the continued forward movement of the driver as the vehicle came to a sudden stop.

The examination of the restraint system on the driver's side indicated it was not in use at the time of impact. This is also consistent with the injuries suffered by the driver and the observed damage to the interior of the vehicle. It is also consistent with the on scene CHP motorcycle Officer's observations of no seat belt on the driver as the vehicle was extracted from its precarious position.

Mechanism of Injury
Passenger

The injuries received by the passenger were consistent with his continued forward motion as the vehicle came to a sudden stop. The following injuries were related to the occupant contact areas mentioned.

1. The injuries to his legs were consistent with the damage noted on the right side dash area of the vehicle.
2. The injury to his left hip and left rib cage were consistent with wearing the restraint system. The laceration and fracture to his hip were consistent with the latching mechanism making contact with the hip. The left rib injury was consistent with contact between the shoulder belt and rib.

The injuries received were consistent with the restraint system being worn loosely. It is apparent that the passenger struck several areas within the vehicle. It is also apparent that he had the provided restraint on as indicated by the injuries in #2 above.

The CHP motorcycle officer also stated that the seat belt was on when he observed the passenger in the vehicle as it was being pulled up.

Vehicle Mechanical Inspection

A mechanical inspection did not reveal any defects that could have caused or contributed to this collision. The vehicle was generally poorly maintained, but that was not considered a causitive factor in this collision.

Conclusions

The investigation conducted by the Central Division MAIT Team concluded that the primary cause of this collision was the speed at which the Mercury Zephyr was being driven.

The driver violated the Basic Speed Law by driving at a speed greater than was reasonable and prudent because:

1. Unusual circumstances existed on the bridge following the earthquake.
2. Traffic conditions were no longer in a normal flow pattern on either deck.
3. The driver had knowledge of the unusual traffic pattern on the westbound upper deck.
4. The driver was driving the wrong way on a five lane bridge, which altered the lawful and designed use of the westbound deck. Any lane or lanes that were occupied by eastbound traffic would have reduced the normal lawful available lanes for westbound traffic.
5. The driver was driving faster than surrounding traffic, and passed a vehicle proceeding in her direction.
6. The driver's attentiveness and reactions to the traffic, pedestrians and highway conditions existing on the bridge following the earthquake were minimal.

XTRA

The failed portion of the Cypress Street Viaduct, between 16th and 32nd streets

Map copyrighted 1980 by the California State Automobile Association. Reproduced by permission.

Scene Identification I-880

Interstate 880 is a north-south connector freeway in the San Francisco Bay area, running from the Junction Route 280, Stevens Creek Boulevard Interchange in Santa Clara County, to the Alameda County junction of Route 80 in Oakland. This freeway provides access for East Bay communities to the city of San Francisco via the Bay Bridge in the north, South Peninsula community access via the San Mateo and Dunbarton bridges, and San Jose and Central California access via its southern connections. The portion of I-880 covered in this summary is called the Cypress Street Viaduct and is located in the city of Oakland.

The Cypress StreetViaduct is a bi-level structure constructed so that the southbound roadway is located above the northbound roadway.

The area land use on both sides of the highway at this location is mixed industrial/commercial, with some urban residential.

The collapsed portion of the Cypress Street Viaduct was located between 16th Street and 34th Street in the city of Oakland. The impacted area lies between column support assembly (Bent) numbers 62 and 113 inclusive.

This portion of I-880 runs southwest to northeast and is located between Postmiles 33.3 and 34.0 in Alameda County.

Structure Description

The Cypress Street Viaduct is a conventionally reinforced, portland cement concrete, box girder design, conforming to American Association of State Highway Officials (A.A.S.H.O.) and California Division of Highways specifications in effect on August 1954. The collapsed portion was typically a bi-level structure, with 52 foot wide upper and lower roadbeds, supported by conventionally reinforced rectangular concrete columns, variably spaced from 68 feet to 90 feet on centers.

The basic structure of the Cypress Street Viaduct changed configuration over 19 times along the collapsed portion from 18th to 34th Street. An examination of the "As Built Plans" dated July 26, 1957, indicates that these design changes were the result of variations in the roadway alignment and span length, as well as plans for future construction, proposed at the time, which would have connected with the west side of the Cypress structure in the general area of W. Grand Avenue.

Roadway General Description

The collapsed sections of the Viaduct were an eight-lane urban expressway with four lanes of travel each for northbound and southbound traffic. The roadway generally consisted of twelve foot wide travel lanes, one foot wide paved shoulders and two-foot six-inch concrete parapets with raised walkways and tubular hand railings.

Speed Limit

The speed limit for the Cypress Street Viaduct was posted at 55 MPH.

Traffic Volumes

The Annual Average Daily Traffic Volume on the Cypress Street Viaduct between the 14th and 32nd Street Connections was 171,000 vehicles per day. The peak hourly volume was 15,400 vehicles per hour. These are total volumes in both directions of travel for 1988 as shown in the Caltrans "1988 Traffic Volumes on California Highways" booklet.

Pre Earthquake

On October 17, 1989, the afternoon commute traffic was lighter than usual for the Bay Area. The lighter than normal traffic can be attributed to the third game of the World Series between the Oakland "A"s and the San Francisco Giants in San Francisco. A large number of people were already at the stadium and an equally large number left work early to become involved in pre-game activities or to watch the game on television.

The weather was nearly perfect, with temperatures in the mid 70's and a mild wind blowing from the northwest. The average speed was approximately 57 mph for southbound traffic and 54 mph for northbound traffic. The spacing between vehicles was normal for these speeds.

At Earthquake

At approximately 1704 hours, the 1989 Loma Prieta Earthquake struck. For many motorists, the first indication of the earthquake came when the radio stations they were listening to went off the air. This was immediately followed by a light, moderate, or violent shaking of their vehicles. The intensity of the vehicle's motion was dependent on their location within the Greater Bay Area.

On the Cypress Structure, drivers and passengers began to feel their vehicles sway from side to side and begin to bounce up and down. The majority of these drivers felt they were experiencing some sort of tire or mechanical failure and began to slow their vehicles to a stop.

Within a very short time span, just four to six seconds after the beginning of the earthquake induced motion of their vehicles, the majority of the upper deck, from 18th Street to 32nd Street, collapsed and fell to the lower deck. None of the drivers on the upper or lower deck had time to bring their vehicles to a stop before the onset of the structure collapse.

Typically, the motorists traveling on the southbound upper deck rode the upper deck down as it collapsed to the lower deck; then continued to decelerate until they either brought their vehicle to a stop, struck some exposed portion of the structure, struck another vehicle, or launched from the upper deck to the surface streets below.

The motorists who were traveling on the northbound lower deck were also decelerating, and before their vehicles could be brought to a stop one of the following things happened: the vehicle ran head-on into a collapsing bent cap and was then crushed downward by the span above them, the vehicle was crushed by a falling bent cap or span, or the vehicle ran into an exposed section of the roadway or guardrail.

Post Earthquake

Within fourteen seconds of the onset of the strong motion of the structure, all vehicle motion came to a stop. Six of the forty-nine southbound vehicles launched from the upper deck and fell to the surface street below. Fifty-three of the fifty-eight northbound vehicles were crushed by the upper deck collapsing on the lower deck. Fires engulfed seven vehicles at five separate locations along the structure.

The majority of people on the upper deck were unable to get off the structure. Similarly, those people on the lower deck who were not trapped in their vehicles were unable to leave the structure unassisted.

Access to the structure was limited by fallen vehicles and debris from the collapsed structure between 18th Street and 32nd Street. Intersecting surface streets were clogged with onlookers, volunteers and their vehicles who were responding from nearby homes and businesses. Access from standing portions of I-880 was hampered by the gridlocked traffic north and south of the collapse.

Pick-up truck at span 107 of Cypress Street Viaduct upper deck, "Big-rig" tractor-trailer at span 109

Police and fire personnel were responding to numerous emergencies throughout the Bay Area and Oakland. The initial reports of widespread damage, combined with an almost total communications blackout, severly limited the number of personnel who were dispatched to any one incident.

California Highway Patrol and Oakland Police officers arrived at the structure within minutes of the collapse. However, they had difficulty accessing the structure since normal routes of ingress and egress were blocked or destroyed by the collapse. When they did gain access, they immediately became involved in life saving efforts and began attempting to rescue and treat the severly injured.

Volunteers from surrounding businesses and residences responded with ropes, ladders and forklifts. They immediately scaled the structure to gain access to the injured on the upper and lower decks. As reports of the collapsed structure were confirmed, police, fire and Caltrans personnel also responded to the scene and began rescue and evacuation operations.

People on the collapsed sections of the upper deck congregated in small groups. The location of the groups, as well as the numbers in each group, appear to have been a function of their ability to gain access to certain portions of the collapsed structure.

The less severely injured tended to the more seriously injured until help arrived. By most accounts, this was approximately 15-20 minutes.

A few people at the southern end of the collapsed section of the upper deck walked off the structure via the northbound 14th street on-ramp or other locations along the structure. Survivors climbed down ladders provided by volunteers or fire department personnel. A few survivors climbed down collapsed support columns and one person actually jumped into a tree adjacent the structure and climbed to the ground.

A number of people on the collapsed lower deck were trapped in their crushed vehicles and could not free themselves. Others managed to free themselves from their vehicles, but could not get off their section of the lower deck.

The majority of these people climbed down ladders provided by volunteers and fire department personnel. One brave volunteer coaxed a female victim into jumping from the structure into his arms on the street below. He caught and broke her fall.

Those victims trapped in their vehicles who could be reached were rescued by groups of volunteers, police officers, and fire department personnel. These rescues ranged from just a few minutes to as long as five hours. Rescue operations were hampered by the instability of the collapsed structure, limited access to crushed vehicles, and cramped work spaces.

Doctors, nurses, and emergency medical technicians set up triage points adjacent to the structure. The majority of the injured were taken to these points for initial evaluation and treatment. They were then transported as needed by helicopters, ambulances, taxicabs, transit buses, and private passenger vehicles. Transportation of the injured was difficult because of the number of victims requiring transportation and poor egress to and from the area.

As the chaos subsided, police, fire department, military and Caltrans personnel initiated a systematic search of the crushed lower deck for survivors. The majority of survivors were located and removed by midnight, October 17, 1989. However, in spite of the modern search and rescue technology used to locate possible survivors, one man was not discovered until the morning of October 21st. Once discovered, his rescue took nearly 4 hours. He survived in the hospital until November 18, 1989, when he succumbed to complications from his injuries.

Search and rescue operations continued until October 21, 1989, when it became apparent that there were no more survivors.

Locating, identifying and removing deceased parties began on October 17 and continued through November 5, 1989. Recovery operations required cutting through the upper deck to access the trapped vehicle, or complete dismantling of the structure. Removal of the vehicles was completed on November 7, 1989.

After rescue, recovery and investigation were completed, the structure was demolished and removed. It has been replaced by a system of surface streets. At the time of this report, the final decision as to a replacement highway or freeway structure has not been made.

Data Analysis

Involved Driver and Passenger Interviews

This summary is based on information obtained from the interviews of the drivers, passengers and witnesses associated with the collapse of the Cypress Structure. This data represents the summary of the actual responses to questions asked of each individual interviewed.

No attempt was made to standardize or otherwise adjust the responses to the questions asked. Inferences made from the data presented are, for the most part, based on the most common response to the question asked or the information provided.

In total, 202 persons were interviewed during the investigation of the Cypress Structure collapse. Of these, 68 were drivers and 24 were passengers on the portion of the Cypress Structure that collapsed. Nine were drivers of vehicles on surface streets adjacent to the structure that were struck by falling concrete and/or other debris. The remaining 101 people are witnesses who were on I-880 prior to the structure collapse, on adjacent freeways, or at various other locations adjacent to the fallen structure.

Traffic Flow

- The traffic flow on the southbound (upper deck) of the Cypress Structure was much lighter than the normal traffic flow on this route for this hour and day of the week. Based on driver and passenger interviews, it is estimated that the traffic density, at the time of the earthquake, was approximately 28 vehicles per lane per mile.

- The traffic flow on the northbound (lower deck) of the Cypress Structure was also much lighter than the normal traffic flow on this route for this hour and day of the week. Based on driver and passenger interviews, the traffic density at the time of the earthquake is estimated to be approximately 27 vehicles per lane per mile.

Speed of Travel

- Based on involved driver statements, the average speed for southbound traffic on the collapsed portion of the Cypress Structure just prior to the earthquake was approximately 57 mph. This average speed is corroborated by witness statements that give the average speed for southbound I-880, south of the collapsed area, of approximately 59 mph and southbound I-880, north of the collapsed area, of 56 mph.

- Based on involved driver statements, the average speed for northbound traffic on the collapsed portion of the Cypress Structure was approximately 54 mph. This average speed is corroborated by witness statements that give the average speed for northbound I-880, south of the collapsed area, of approximately 57 mph and northbound I-880, north of the collapsed area, of 51 mph.

First Response to the Earthquake

- On both the southbound upper deck and northbound lower deck of the collapsed portion of the Cypress Structure, the most common initial reaction to the earthquake induced motion of

the structure was a light to moderate braking. This was typically in response to what was felt, by the driver, to be a flat tire or vehicle mechanical failure.

- Witnesses, who were northbound and southbound on I-880, north and south of the collapsed portion of the structure when it collapsed, also responded initially by a light to moderate braking to what they initially believed to be a flat tire or vehicle mechanical failure.

Vehicle Motion

- For those drivers and passengers who were on the Cypress Structure when it collapsed, the most common initial vehicle motion experienced was a side-to-side movement. This was true for both the upper and lower decks.

- Approximately 80 percent of the drivers and passengers, who were on the Cypress Structure when it collapsed, recall feeling a vertical motion in addition to the lateral motion they experienced.

- The majority of the upper and lower deck drivers and passengers, who recall feeling vehicle motion as a consequence of the earthquake, indicated they felt the lateral motion first followed by the vertical motion.

- The initial vehicle motion experienced by the witnesses, who were drivers and passengers on I-880, north and south of the collapsed Cypress Structure when the earthquake struck, was very similar to the initial vehicle motion experienced by drivers and passengers who were on the Cypress Structure when it collapsed.

Falling Sensation

- As would be expected, a majority of the drivers and passengers, who were on the upper deck of the Cypress Structure when it collapsed, recall feeling a falling sensation prior to their vehicles coming to rest.

- Also, as would be expected, very few lower deck drivers or passengers indicated experiencing a falling sensation.

Structure Motion

- The most prominent observation of structural motion for involved drivers and passengers on the upper deck of the Cypress Structure was a swaying of the structure in a lateral direction and a wave and bouncing motion in the vertical direction.

- There were very few responses from those involved drivers and passengers who were on the lower deck with respect to the motion of the structure. Of those that did respond to questions concerning the lateral motion of the structure, two stated it was swaying and two indicated that it was rocking. With respect to the vertical motion of the structure, the two most common responses were a wave-like motion and a bouncing movement.

- For witnesses who were southbound, north and south of the

collapsed portion of the structure when the earthquake struck, the most common response with respect to the lateral motion of the structure was a swaying action. The most common response with respect to the vertical motion of the structure was a bouncing motion.

- For witnesses who were northbound, north and south of the collapsed portion of the structure when the earthquake struck, the most common description of the vertical motion of the structure was a wave-like motion.

Structure Failure

- In describing the failure of the structure, the most common description from upper deck drivers and passengers was a failure on the east side, followed by a failure on the west side.

- For involved drivers and passengers, who were northbound on the Cypress Structure, the most common sensation, or observation, of the structure failure was a simultaneous collapse of the portion of the structure immediately above them.

Data Analysis

Fatalities, Injuries, and Vehicle Damage

This investigation identified 116 vehicles, with a total of 171 people, that were directly involved in the earthquake induced collapse of the Cypress Structure. There were 49 vehicles with 85 people on the southbound upper deck, 58 vehicles with 77 people on the northbound lower deck, and nine vehicles with nine people on the surface streets immediately adjacent to the structure.

Number of People Killed, Injured and Uninjured

There were a total of 42 people killed and 108 people injured as a direct result of the collapse of the Cypress Structure. There were 21 people reportedly uninjured.

Of the 42 people killed, 35 were on the northbound lower deck. There were no fatalities among the drivers of surface street vehicles. Of the 108 people injured, 67 were on the southbound, upper deck, 38 were on the northbound, lower deck, and three were on surface streets immediately adjacent to the structure.

Severity of Injury
All Injured Parties

Of the 108 people injured, 56 people suffered severe injury, 29 suffered other visible injury, and 23 people complained of pain.

Severity of Injury
Southbound Injured Parties

Of the 67 southbound, upper deck injuries, 34 were severe, 19 were other visible injury, and 14 were classified as complaint of pain.

Severity of Injury
Northbound Injured Parties

Of the 38 northbound, lower deck injuries, 21 were severe, 10 were other visible injury, and seven (7) were classified as complaint of pain.

Severity of Injury
Surface Street Injured parties

Of the 3 people injured on surface streets immediately adjacent to the Cypress Structure, one suffered severe injury and two people complained of pain.

Severity of Damage to Vehicles
All Involved Vehicles

Of the 116 vehicles directly involved in the collapse of the Cypress Structure, 75 sustained total damage, 16 sustained major damage, 19 sustained moderate damage, five sustained minor damage, and one vehicle sustained no damage.

Severity of Damage to Vehicles
Southbound Involved Vehicles

Of the 49 vehicles that were southbound on the upper deck of the Cypress Structure, 18 sustained total damage, 12 sustained major damage, 15 sustained moderate damage, three sustained minor damage, and one vehicle sustained no damage.

Severity of Damage to Vehicles
Northbound Involved Vehicles

Of the 58 vehicles that were northbound on the lower deck of the Cypress Structure, 54 sustained total damage, one sustained major damage, two sustained moderate damage, and one sustained minor damage.

Severity of Damage to Vehicles
Surface Street Involved Vehicles

Of the nine vehicles on surface streets immediately adjacent to the Cypress Structure, three sustained total damage, three sustained major damage, two sustained moderate damage, and one sustained minor damage.

I-880 CYPRESS STRUCTURE COLLAPSE - Summary Sheet

Southbound Direction (Upper Deck)

Occupant Summary			Vehicle Summary	
Total Number of Involved Parties:		85	Total Number of Involved Vehicles:	49
Total Number of Fatalities:		7	Number With Total Damage:	18
Total Number of Injuries:		67	Number With Major Damage:	12
Number With Complaint of Pain:	14		Number With Moderate Damage:	15
Number With Other Visible:	19		Number With Minor Damage:	3
Number With Severe:	34		Number With No Damage:	1
Total Uninjuried:		11		

Northbound Direction (Lower Deck)

Occupant Summary			Vehicle Summary	
Total Number of Involved Parties:		77	Total Number of Involved Vehicles:	58
Total Number of Fatalities:		35	Number With Total Damage:	54
Total Number of Injuries:		38	Number With Major Damage:	1
Number With Complaint of Pain:	7		Number With Moderate Damage:	2
Number With Other Visible:	10		Number With Minor Damage:	1
Number With Severe:	21		Number With No Damage:	0
Total Uninjuried:		4		

Surface Streets

Occupant Summary			Vehicle Summary	
Total Number of Involved Parties:		9	Total Number of Involved Vehicles:	9
Total Number of Fatalities:	0		Number With Total Damage:	3
Total Number of Injuries:	3		Number With Major Damage:	3
Number With Complaint of Pain:	2		Number With Moderate Damage:	2
Number With Other Visible:	0		Number With Minor Damage:	1
Number With Severe:	1		Number With No Damage:	0
Total Uninjuried:		4		

Totals

Occupant Totals			Vehicle Totals	
Total Number of Involved Parties:		171	Total Number of Involved Vehicles:	116
Total Number of Fatalities:	42		Number With Total Damage:	75
Total Number of Injuries:	108		Number With Major Damage:	16
Number With Complaint of Pain:	23		Number With Moderate Damage:	19
Number With Other Visible:	29		Number With Minor Damage:	5
Number With Severe:	56		Number With No Damage:	1
Total Uninjuried:		21		

Witnesses

Southbound I-880	Northbound I-880	Off Structure	Total
32	55	14	101

Data Analysis

Vehicle Impact and Collision Types

The following impact and collision type summary is based on an evaluation of the available physical evidence, the points of rest of involved vehicles with the damage they sustained, as well as information provided by interviews with the drivers and passengers who were on the Cypress Structure when it collapsed.

Southbound Upper Deck Vehicle Impact and Collision Types

Twenty eight of the 49 southbound upper deck vehicles were involved in multiple impacts with the roadway surface, exposed portions of the freeway structure, barrier rails, etc., and in some cases, other vehicles. The remaining 21 vehicles were primarily involved in only one type of injury and/or damage producing incident.

Fifteen upper deck vehicles were involved in six vehicle-to-vehicle collisions. Each of these collisions were directly associated with the collapse of a section of the freeway structure. Seventeen vehicles ran into or made contact with an exposed section of the freeway structure, such as an off-set between roadway levels, an exposed expansion joint, etc. Thirty-three vehicles impacted the roadway surface with sufficient force to produce injury and/or vehicle damage. The majority of these impacts occurred as the structure fell out from beneath the vehicle, or the vehicle launched over a raised section of roadway and came back down to impact the roadway surface. Six upper deck vehicles impacted a side barrier rail. There were six vehicles that fell or were launched from the upper deck to the surface streets below. Four of these vehicles left the east side of the upper deck at Span 75 or at Bent 76. One vehicle left the west side of the upper deck at Span 98, and one vehicle left the west side of the upper deck at Span 105. Four vehicles overturned as a result of being tripped by an exposed portion of the roadway surface. One vehicle on the upper deck was subsequently destroyed by fire.

Northbound Lower Deck Vehicle Impact and Collision Types

On the lower deck, there were no significant multiple impacts as a result of the earthquake induced motion of the structure. The majority of the vehicles on the lower deck were involved in one primary injury and/or damage causing incident.

Of the 58 vehicles on the lower deck when the structure collapsed, 21 drove to impact with a falling bent cap. Two vehicles impacted an exposed section of the freeway structure. Twenty vehicles were crushed primarily by a falling span, and 13 vehicles were primarily crushed by a falling bent cap. One vehicle impacted a barrier rail and one vehicle was damaged by falling concrete debris. There were a total of six vehicles on the lower deck that were damaged or destroyed by fire.

Surface Street Vehicle Impact and Collision Types

Of the nine involved vehicles on the surface streets immediately adjacent to the Cypress Structure, two were crushed by a falling column, five were struck by falling concrete debris, one was crushed by a falling barrier rail; and one vehicle was struck by a truck that had fallen from the upper deck.

Vehicle Fire Locations

In total, there were seven vehicles damaged or destroyed in five separate fires that resulted from the collapse of the Cypress Structure. The primary fuel source for these fires came from collapsed or damaged fuel reservoirs of the involved vehicles. The ignition source for these fires was not determined as a result of this investigation.

Only one fire of significance was associated with the southbound, upper deck of the freeway. This involved V-40,

a 1983 Chevrolet Cavalier, and occurred to the west side of Span 105 after the vehicle came to rest.

On the lower deck, there were four fires of significance. One fire was in Span 106 and involved V-54, a 1989 Kenworth tractor and 1989 Grotto trailer; and V-56, a 1985 Toyota Camry. Another fire was in Span 99 and involved V-69, a 1988 Acura Legend. There was a fire in Span 86 which involved V-87, a 1987 Ford Escort, and V-88; a 1986 BMW 325. There was also a fire at Bent 67 involving V-98, a 1980 Toyota SR5 sedan.

The following chart summarizes the fire locations and vehicles involved:

Bent/ Span	Number of Vehicles	Direction on I880
67	1	Northbound Lower Deck
86	2	Northbound Lower Deck
99	1	Northbound Lower Deck
105	1	Southbound Upper Deck
106	2	Northbound Lower Deck

Seatbelt Usage and Injury Severity

Approximately 64.5 percent of all drivers and passengers directly involved in the collapse of the Cypress Structure were reportedly using their seatbelts when the earthquake struck. The seatbelt use on the southbound upper deck was approximately 77.6 percent and approximately 49.5 percent on the northbound lower deck. The seatbelt usage for approximately 5.8 percent of involved drivers and passengers could not be determined. As the majority of these drivers and passengers were on the northbound lower deck, it is possible that the percentage of occupants using restraint systems on the lower deck was greater than the reported 49.5 percent. Approximately 66.7 percent of the involved drivers and passengers on the surface streets immediately adjacent to the Cypress Structure were wearing their seatbelts.

A comparison of injury severity to seatbelt use for all involved drivers and passengers indicates that restrained occupants were, on average, twice as likely to be uninjured as were their unrestrained counterparts.

Of particular interest was the comparison of the percentage of fatal injuries suffered by restrained and unrestrained occupants. On average, the percentage of unrestrained occupants who suffered fatal injuries was twice that of restrained occupants.

The percentage of restrained occupants suffering "other visible" and "severe" injuries was greater than their unrestrained counterparts. However, this anomaly can be contributed to the fact that a larger percentage of restrained occupants survived than did unrestrained occupants, adding to the percentage of restrained occupants suffering other than fatal injuries.

Not surprisingly, seatbelts save lives. Not only in traffic collisions, but during catastrophic events such as earthquakes.

The charts on the following page compare the injurity severity for restrained and unrestrained occupants.

Injury Severity - Comparison of Restrained and Unrestrained Occupant Injuries

The following charts compare injury categories, by percent injured, for restrained and unrestrained occupants of vehicles directly involved in the earthquake induced collapse of the Cypress Street Viaduct.

Injury Classification	Restrained	Unrestrained
Uninjured	15.5 %	6.0 %
Complaint of Pain	13.6 %	16.0 %
Other Visible Injury	20.9 %	12.0 %
Severe Injury	35.5 %	28.0 %
Fatal Injury	14.5 %	38.0 %

Injury Severity - Restrained vs. Unrestrained Occupants
All Involved Parties

Injury Classification	Restrained	Unrestrained
Uninjured	16.7 %	3.0 %
Complaint of Pain	13.6 %	26.3 %
Other Visible Injury	25.8 %	10.5 %
Severe Injury	36.4 %	52.6 %
Fatal Injury	7.6 %	10.5 %

Injury Severity - Restrained vs. Unrestrained Occupants
Southbound Parties

Injury Classification	Restrained	Unrestrained
Uninjured	7.9 %	3.4 %
Complaint of Pain	10.5 %	10.3 %
Other Visible Injury	15.8 %	13.8 %
Severe Injury	36.8 %	13.8 %
Fatal Injury	28.9 %	58.6 %

Injury Severity - Restrained vs. Unrestrained Occupants
Northbound Parties

Injury Classification	Restrained	Unrestrained
Uninjured	50.0 %	100.0 %
Complaint of Pain	33.3 %	0.0 %
Other Visible Injury	0.0 %	0.0 %
Severe Injury	16.7 %	0.0 %
Fatal Injury	0.0 %	0.0 %

Injury Severity - Restrained vs. Unrestrained Occupants
Surface Street Parties

Time to Structure Collapse

Driver and passenger statements, along with an evaluation of the available physical evidence, strongly suggests that none of the vehicles on the section of the Cypress Structure that collapsed had time to bring their vehicles to a stop prior to the beginning of the earthquake induced collapse of the structure.

The vehicles on the upper deck had slowed from an average speed of 57 mph to an average speed of 38 mph when the structure collapsed. The lower deck vehicles were able to slow from an average speed of 54 mph to an average speed of 32 mph when the structure began to collapse.

The majority of the drivers, passengers and witness accounts of the structure failure indicated that the collapse occurred very shortly after they began to feel the structure move.

The analysis of vehicle motion, from the beginning of perception of vehicle motion to the vehicle's final position of rest, indicates that the structure failed somewhere between 4 to 6 seconds after its movement became perceivable to the drivers and passengers who were on the structure when it collapsed.

The total time of vehicle motion, from the onset of perceptible vehicle motion, to the point where the vehicle came to rest, varies greatly, depending on the location and particular motion of each of the involved vehicles. These times range from as little as four (4) seconds for those vehicles that ran into immovable objects such as bent caps or exposed sections of the structure, to as much as 14 seconds for those vehicles that bounced, rolled, and/or slid to their final positions of rest without striking any significant portion of the structure.

Time of Earthquake Induced Structure Motion

The total time of earthquake induced structure motion could not be determined by this investigation. When the structure collapsed, all of the vehicles on the Cypress Structure were still in motion. After the structure had collapsed, those vehicles that had not impacted an exposed portion of the structure, or were not crushed as a consequence of a fallen span or bent cap, were still in motion. These vehicles continued in motion on the collapsed structure, bouncing, yawing or sliding across a broken, twisted and bent roadway. It was impossible to separate the driver's and passenger's sensation of motion associated to their post collapse vehicle motion from any post collapse earthquake induced structure motion.

Relationship of Earthquake Induced Ground Motion to Earthquake Induced Structure Motion

The time from the onset of earthquake induced ground motion to the onset of earthquake induced structure motion was not determined from the data collected and evaluated in this investigation. Consequently, the times referred to in this investigation report are taken from the instant the motorist began to experience earthquake induced vehicle motion to the onset of the event being evaluated (i.e., the beginning of an evasive maneuver, the beginning of structure collapse, the total duration of vehicle motion).

Time-Position Analysis

Involved Drivers

Most of the people interviewed were unable to accurately estimate the duration of the motion they felt during the earthquake. The time estimates that were given for this motion varied from just a few seconds to well over one minute. It is clear, from a review of the interviews conducted, that a meaningful estimate of the time of the motion of the Cypress Structure, or the time to its collapse, could not be obtained from the time estimates given by the majority of the drivers, passengers or witnesses interviewed.

While those interviewed could not give an accurate estimate of the duration of motion, the majority of those interviewed could give an accurate description of their lane and speed of travel, the earthquake induced motion they felt, and their response to that motion.

Approximately 48.5 percent of the drivers on the collapsed section of the Cypress Structure felt they were experiencing a flat tire as the earthquake struck. Another 4.4 percent thought they were experiencing a tire and/or mechanical failure. The majority of these drivers responded to the earthquake induced motion of their vehicles as if they had actually experienced a tire and/or mechanical failure, and tried to bring their vehicles under control accordingly. The uniformity of the evasive maneuvers taken by the drivers on the Cypress Structure is evident in the fact that there were relatively few vehicle-to-vehicle impacts as a consequence of driver reaction to the earthquake.

Before the vast majority of the drivers on the Cypress Structure could bring their vehicles under control, the structure collapsed, causing their vehicles to become involved in one or more of the following:

1. Collide head-on into a portion of the collapsed roadway, or viaduct structure, and come to rest.

   On the lower deck (N/B), this collision was typically with a bent cap. On the upper deck (S/B), the collision was typically with a fractured portion of the roadbed, or a portion of the structure that was at a higher elevation than the portion of the structure on which the vehicle was being driven.

   A few impacts on the upper deck involved impact into another vehicle.

2. Begin braking then strike a fractured portion of the roadway, or viaduct structure; continue on past the impact site, braking, or otherwise decelerating to a stop.

3. Launch, or fall, as the structure fell out from underneath them, then land and bounce out of control to a stop or into impact with some portion of the viaduct structure.

4. Experience a lateral and/or vertical motion and brake, or otherwise decelerate to a stop.

5. Experience a lateral and/or vertical motion and then go out of control, impact a portion of the structure, and/or launch off of the structure to the surface street below.

6. A combination of one through five, above.

Vehicle Motion Analysis - Methodology

The pre, at, and post-collapse motion of 50 of the 116 involved vehicles was reconstructed using the following data: the available physical evidence (skidmarks, etc.); known vehicle impact and point of rest positions; location of significant (impassible) structure damage; as well as, the driver's and passenger's statements regarding speed, lane of travel; and evasive actions taken as a consequence of the earthquake induced vehicle motion.

Time-Position Analysis - Methodology

A time-position study was conducted for each of the vehicles for which a motion analysis was completed. The time-position studies were conducted using standard accident reconstruction techniques based on the laws of physics and the equations of motion with constant acceleration.

The time-position calculations varied from vehicle to vehicle, dependant upon their reconstructed motion. However, the majority of the calculations were typically handled in four phases.

Phase I	Perception and reaction
Phase II	Initial evasive maneuver
Phase III	Impact with a portion of the structure or other object
Phase IV	Post impact deceleration to a stop.

Phase I, perception and reaction, calculations were based on a typical driver's response to a tire and/or a mechanical failure. The average driver typically takes from 0.7 to 1.4 seconds to perceive the fact that he or she has had a tire failure, with an average time of perception of approximately one second. Once the driver perceives the tire failure, his or her normal response is to take his or her foot off of the gas pedal and move it to the brake pedal. This normally takes from 0.1 to 0.3 seconds, with the norm being toward the high side of this range, or 0.3 seconds. During this period of time the vehicle would be decelerating at an engine and rolling resistance deceleration rate appropriate for the given speed of travel. At the average speeds on the Cypress Structure, this would be a deceleration rate of approximately 3 feet-per-second squared (0.1g).

Phase II, initial evasive maneuver, calculations were also based on a typical driver's response to a tire and/or a mechanical failure. The normal driver will then begin braking his or her vehicle at a relatively low deceleration rate, typically somewhere between 7 to 10 feet-per-second squared (0.22 to 0.31g) , with the tendency to brake at the lower rate of 7 feet-per-second squared. The driver will normally continue braking at this rate until the vehicle has slowed to somewhere around 10 mph. Once the vehicle has slowed to this speed, the driver will typically begin braking harder and will continue this braking level until the vehicle comes to a stop. This last period of braking is typically at a deceleration rate below the locked wheel threshold and is normally somewhere around 15 feet-per-second squared (0.47g).

Phase III, impact with a portion of the structure or other object, calculations were normally based on speed change (delta V) estimates, or calculations, from vehicle damage sustained at impact by the vehicle of interest.

Phase IV, post impact deceleration to a stop, calculations were, for the most part, based on the available post impact physical evidence (skidmarks, etc.), and deceleration rates were established accordingly.

Time-position studies were conducted only for those vehicles where

it was felt adequate evidence of vehicle motion and driver reaction was present.

The numbering in the following chart matches the numbering in the original report, and can be used to cross reference for more detailed information.

The following spreadsheet form gives an example of the results of calculations for vehicles 20, 21, 23, 24, 25 and 26.

Vehicle Number	V-20	V-21	V-23	V-24	V-25	V-26
Initial Velocity (mph)	55	65	55	55	55	55
Initial Velocity (fps)	80.69	95.36	80.69	80.69	80.69	80.69
Perception Time (sec.)	1	1	1	1	1	1
Perception Distance (ft)	80.69	95.36	80.69	80.69	80.69	80.89
Reaction Time (sec.)	0.3	0.3	0.3	0.3	0.3	0.3
Deceleration Rate - Engine Braking (fps/s)	3	3	3	3	3	3
Deceleration Distance (ft)	24.07	28.47	24.07	24.07	24.07	24.07
End Velocity (fps)	79.79	94.46	79.79	79.79	79.79	79.79
Deceleration Rate - Light Braking (fps/s)	7	7	7	7	7	7
Velocity - End of Light Braking (mph)	43.81	52.94	17.65	44.41	39.92	38.17
Velocity - End of Light Braking (fps)	64.27	77.67	25.89	65.15	58.57	56.00
Deceleration Distance - Light Braking (ft)	159.69	206.41	406.79	151.53	209.69	230.71
Deceleration Time - Light Braking (sec.)	2.22	2.40	7.70	2.09	3.03	3.40
Delta V (mph)	n/a	n/a	10	10	n/a	10
Delta V (fps)	n/a	n/a	14.67	14.67	n/a	14.67
Deceleration Rate - To a Stop (fps/s)	7	13	7	7	7	7
Stopping Distance (ft)	295	232	9	182	245	122
Stopping Time (sec.)	9.18	5.97	1.60	7.21	8.37	5.90
TOTAL DISTANCE TRAVELED (ft)	559	562	521	438	559	457
TOTAL TIME TO STOP (sec.)	12.70	9.67	10.60	10.60	12.70	10.60
TIME TO COLLAPSE (sec.)	4	4	4	5	5	5

Spreadsheet Time-Position Calculations

Traffic Density, Population and at Risk Analysis

Traffic Flow Data - Estimates for a Typical Tuesday in October at 1700 hours
The following information relevant to the traffic conditions on the collapsed portion of I-880 on a typical Tuesday in October at 1700 hours was provided by the Highway Operations Branch of Caltrans, District 4, in San Francisco.

Category	Southbound Upper Deck	Northbound Lower Deck
Vehicles per hour per lane	1509	1400
Vehicles per lane per mile	28	27

Traffic Flow Data - Estimated and Actual Conditions for October 17, 1989, at 1704 hours
The length of the section of the Cypress Structure that collapsed was approximately 4000 feet (0.76 of a mile). There were a total of 49 vehicles and 85 people on the southbound upper deck and 58 vehicles and 77 people on the northbound lower deck of the Cypress Structure when it collapsed. As there are four lanes in each direction of travel on the Cypress Structure, the following information can be derived.

Category	Southbound Upper Deck	Northbound Lower Deck
Vehicles per hour per lane	900	1100
Vehicles per lane per mile	16	19

Traffic Density and Population Estimates
The average vehicle occupancy rate on the Cypress Structure, under typical conditions, is estimated to be approximately 1.25 people per vehicle. Using the data provided above and accepted traffic engineering principles relevant to traffic densities, vehicles per lane per mile and the number of available traffic lanes, the following traffic density and population figures were estimated.

Comparison of Density and Population Estimates for Typical vs. Actual Traffic Conditions

Southbound I-880	Typical Conditions	Actual Conditions	Difference
Density (Vehicles per lane per mile)	28	16	-12
No. of Lanes	4	4	0
Length of Structure (miles)	0.76	0.76	0
No. of Vehicles on the Structure	85	49	-36
Occupancy Rate	1.25	1.74	0.49
No. of People on the Structure	103	85	-18

Northbound I-880	Typical Conditions	Actual Conditions	Difference
Density (Vehicles per lane per mile)	27	19	-8
No. of Lanes	4	4	0
Length of Structure (miles)	0.76	0.76	0
No. of Vehicles on the Structure	82	58	-24
Occupancy Rate	1.25	1.33	0
No. of People on the Structure	103	77	-26

Comparison of Density and Population Estimates for Typical vs. Actual Traffic Conditions

Northbound and Southbound I-880	Typical Conditions	Actual Conditions	Difference
Total No. of Vehicles on the Structure	167	107	-60
Total No. of People on the Structure	209	162	-47

Number of People at Risk

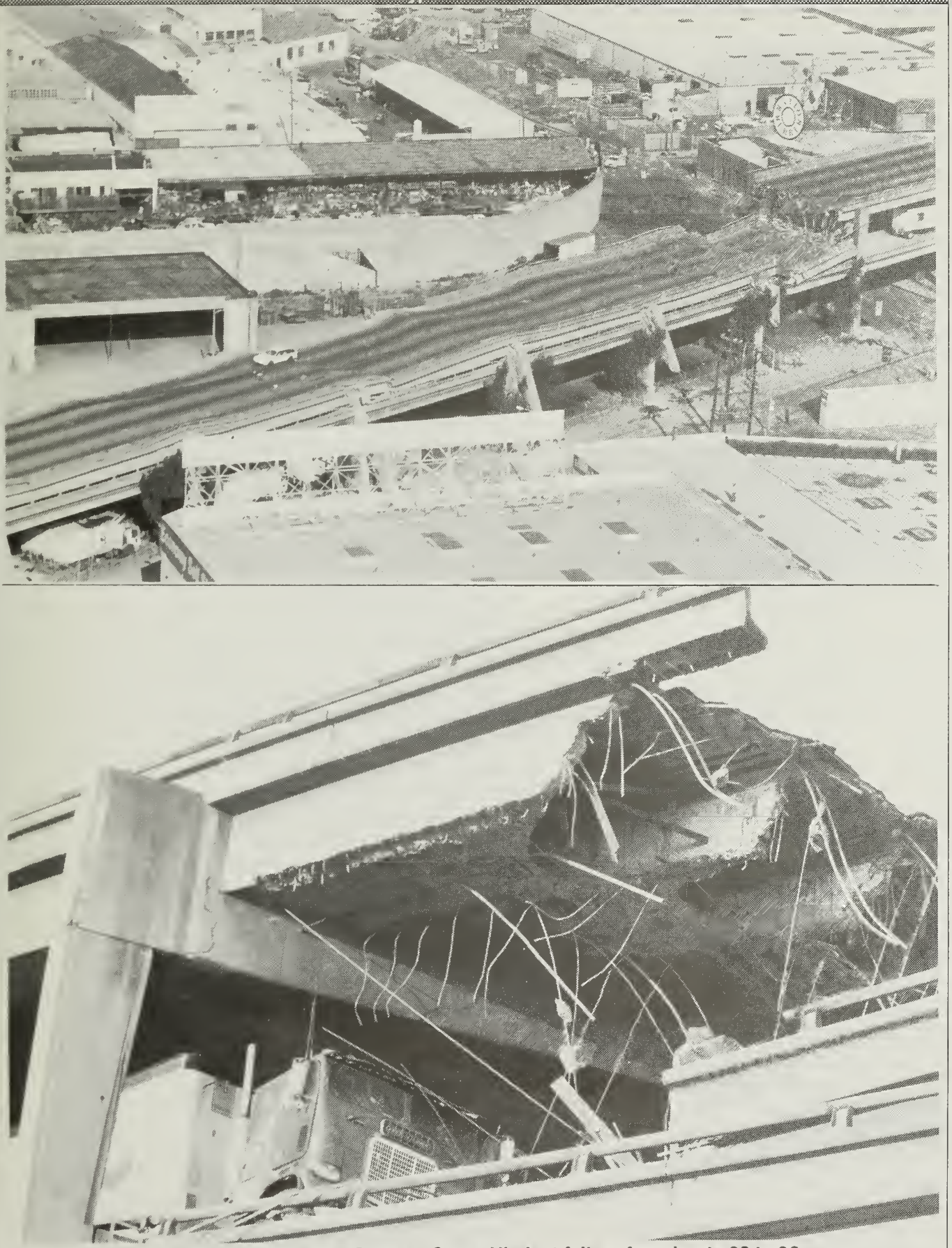
Based on data provided by Caltrans, it is estimated that, given typical traffic conditions, there should have been approximately 167 vehicles and 209 people on the collapsed portion of the Cypress Structure when the earthquake struck. In actuality, there were 107 vehicles and 162 people on the section of the Cypress Structure that collapsed.

Consequently, because of the lighter-than-normal traffic on the Cypress structure when the earthquake struck, there were approximately 60 fewer vehicles and 47 fewer people at risk than there would have been given typical traffic conditions.

Occupancy Rates

The average occupancy rate for southbound traffic on the collapsed section of the Cypress Structure was approximately 1.74 people per vehicle. For northbound traffic it was approximately 1.33 people per vehicle.

Note: Typical conditions based upon data and calculations provided by the Highway Operations Branch, District 4, Caltrans, in San Francisco. Actual conditions based on actual count of involved parties and vehicles located on the collapsed portion of the Cypress Structure.



Top photograph shows the Cypress Street Viaduct failure from bents 90 to 96
Bottom photograph shows a close-up of bent 97 and V-74, a Freightliner tractor/trailer

Collapse Scenario

This collapse scenario is based on an evaluation of the data and information obtained from the following areas:

1) The damage sustained by the structure and the final at-rest location of portions of the structure as compared to their original, as-constructed, location.

2) Eyewitness testimony from drivers, passengers and witnesses who saw, or were actually involved in, the collapse of the structure.

3) Skidmarks, gougemarks, scrape marks, fluid trails, debris, and other physical evidence found on the structure that could be associated with the motion of the vehicles during, and after, the earthquake.

4) The position of rest, and damage sustained by, each of the vehicles on the Cypress Structure when it collapsed.

5) A motion and time-position analysis of involved vehicles on the Cypress Structure for which appropriate information was available.

Eyewitness and survivor accounts of the motion of the Cypress Structure indicated that when the earthquake struck, the structure very quickly began a violent side-to-side swaying motion. There were sufficient witness accounts of a wave-like motion and bouncing to suggest that the side-to-side motion of the structure induced a vertical, wave-like, motion that moved longitudinally through portions of the structure. By all accounts, this motion was violent and lasted for only a very short period of time before the structure began to collapse.

There were at least four separate sites where initiating failure points have been identified. The collapse at these failure sites appear to have occurred nearly simultaneously. The following discussion identifies those sites and discusses the associated progressive failures along the collapsed portions of the structure.

Page 40 is a "Collapse Diagram" to clarify this "Collapse Scenario Summary."

Collapse Scenario Summary

There were four different upper deck sites at which the upper deck support columns failed, and collapsed, approximately four (4) seconds after the structure's strong motion began. These locations are as follows:

1) At Bents 71 and 72.
2) At Bents 73 through 80.
3) At Bents 89 through 92.
4) At Bent 104.

The upper deck failure and collapse at Bents 71 and 72 initiated a southward progressing failure and collapse of the upper deck support columns from Bent 70 through Span 62. The collapse at Span 62 occurred approximately six (6) seconds after the structure's strong motion began, and approximately two (2) seconds after the upper deck failure and collapse at Bents 71 and 72.

The upper deck collapse at Bents 73 through 80 was a partial collapse. Here the east side upper deck support columns failed, while the west side upper deck support column at Bent 73 only partially collapsed, and the west side upper deck support columns at Bents 74 through 80 stayed up. The upper deck collapse at Bents 73 through 80 initiated a northward progressing failure and collapse of upper deck support columns from Bents 81 through 83.

The upper deck collapse at Bents 89 through 92 initiated a northward progressing failure and collapse of upper

deck support columns from Bent 93 through Span 95, and a southward progressing failure and collapse of upper deck support columns from Bent 88 through 84.

The northward progressing upper deck collapse from Bent 81, and the southward progressing upper deck collapse from Bent 88, met in Span 83, between Bents 83 and 84, approximately five (5) seconds after the structure's strong motion began. This was approximately one (1) second after the initiating failures at Bents 80 and 89.

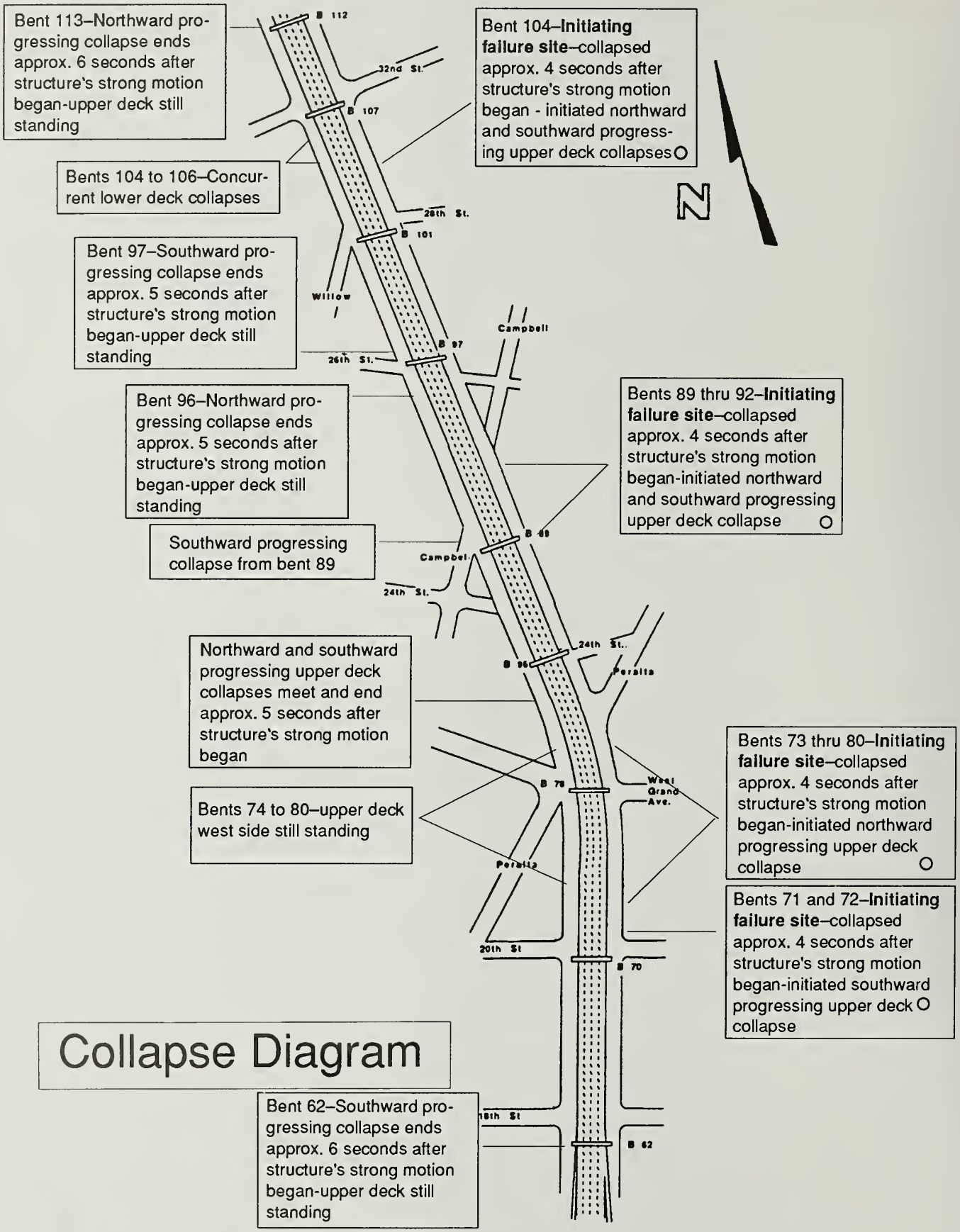
The upper deck failure and collapse at Bent 104 initiated a southward progressing failure and collapse of upper deck support columns from Bent 103 through Span 97, and a northward progressing failure and collapse of upper deck support columns and/or caps from Bent 105 through Span 112.

The northward progressing upper deck collapse from Bent 93, and the southward progressing collapse from Bent 103, ended at Spans 95 and 97. The overhang portion of Span 95 fractured, just south of Bent 96, and collapsed to the lower deck. The upper deck support columns at Bents 96 and 97, although damaged, did not fail and the upper deck did not collapse between Bents 96 and 97. Span 97 fractured and separated, just north of Bent 97, and collapsed to the lower deck with Bent 98. The northward and southward progressing collapses ended approximately one (1) second after their respective initiating failure points at Bents 92 and 104.

The northward progressing upper deck collapse from Bent 104 reached Span 112 approximately six (6) seconds after the structure's strong motion began, and approximately two (2) seconds after the initiating failure and collapse at Bent 104.

There was a complete collapse of the lower deck at Bent 105, and partial collapses of the lower deck at Bents 104 and 106. These lower deck collapses were occurring in the same time frame as the upper deck collapses between Bents 104 and 106. The collapse was completed approximately five (5) seconds after the structure's strong motion began, and approximately one (1) second after the collapse of the upper deck at Bent 104.

The collapse of the Cypress Structure began approximately four (4) seconds after the structure's strong motion began, and was complete approximately six (6) seconds after the onset of the structure's strong motion.

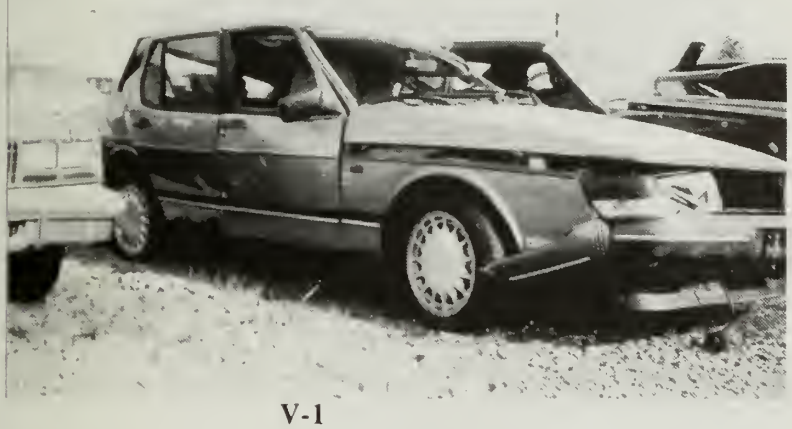


Collapse Diagram

Vehicle Scenarios

During the investigation, 116 individual scenarios were prepared for the drivers, passengers and vehicles directly involved in the events of the earthquake. Of these, six "typical" scenarios were selected to provide the reader with a sense of what happened and how it was addressed.

The vehicle numbering in this summary matches the numbering in the original report, and can be used to cross-reference for more detailed information.



V-1

Just prior to the earthquake, a 32 year-old male was driving a green 1989 Saab 900 southbound on I-880 in the S-3 lane at approximately 65 mph. A 31 year-old female passenger was seated in the right front seat. They were wearing lap/shoulder harness type restraints.

When the structure's strong motion began, the Saab was traversing Span 67. It suddenly began swerving from side to side. The driver began braking moderately and steering in an attempt to control the Saab. As it continued to decelerate, his passenger could see the structure, forward of their vehicle, swaying from side to side and bouncing. She also observed the roadway beginning to crumble and break up.

Approximately four (4) seconds after the beginning of the structure's strong motion, the upper deck support columns began to fail. In this area, a southward progressing collapse of the upper deck had begun at Bent 71.

Approximately six (6) seconds after the structure's strong motion began, V-1 was traversing Span 62 just south of Bent 63 when the upper deck support columns at Bent 63 failed. V-1 had decelerated to approximately 22 mph and was in the S-4 lane when it reached the expansion joint just north of Bent 62. The portion of the span that V-1 was traversing collapsed downward and away from the support span seat. V-1 struck the north face of the support span diaphragm, overturned and slid upside down to a stop.

Approximately nine (9) seconds after the structure's strong motion began, the Saab came to rest on its roof facing northbound in the S-4 lane, approximately 30 feet south of Bent 62.

The passenger released her seatbelt and exited the vehicle through the right rear door. The driver also exited the vehicle through the right rear door. They remained on the structure for a short period of time, then walked off the structure via the southbound 14th Street off-ramp. They walked to an aid station which had been set up on one of the surface streets below the structure. They were subsequently transported to Providence Hospital in Oakland, by ambulance.

The driver reportedly complained of pain in his chest and had multiple contusion and abrasions on his torso. He was treated at Providence Hospital on October 17, 1989, and released on the same date.

The passenger indicated that she had sustained a bump on her head and a bruise on her left leg. She did not receive treatment at Providence Hospital. She decided to go to Kaiser Hospital in Oakland, where she was treated and released on October 17, 1989. The exact nature of her injuries is unknown since she did not sign a medical information release.

The Saab sustained total damage as a result of its impact with the expansion joint's diaphragm and subsequent rollover. The vehicle was towed from the freeway at a later time.

V-40

Just prior to the earthquake, a 32 year-old female was driving a tan 1983 Chevrolet Cavalier southbound on I-880 in the S-4 lane at approximately 60 mph. The Cavalier was equipped with lap/shoulder type restraints, and she was utilizing her's. She indicated that a gray Dodge Van was traveling in the S-4 lane some distance in front of her, and that a black Nissan 300SX had just passed her.

As the structure's strong motion began, the Cavalier was most likely traversing Span 112, since the driver indicated she had just been passed by the 300SX when the structure's strong motion began. She stated that her vehicle suddenly went up in the air as if it had a blowout. She said that she was attempting to control her vehicle which was bouncing up and down erratically. She also noted that the other vehicles in her vicinity were experiencing similar difficulties. She had no recollection of the structure's motion.

Approximately four (4) seconds after the structure's strong motion began, the east side upper deck support column at Bent 104 failed, followed immediately by the west side upper deck support column. The upper deck collapsed at Bent 104, initiating a northward and southward progressing upper deck collapse from Bent 104.

Immediately following the upper deck collapse at Bent 104, and as the ensuing northward progressing upper deck collapses were occurring, there was a partial collapse of the lower deck at Bent 104, a complete collapse of the lower deck at Bent 105, and a partial collapse of the lower deck at Bent 106. These lower deck collapses were completed approximately five (5) seconds after the structure's strong motion began.

The upper deck came to rest on the lower deck at Bent 104 and the lower deck also collapsed downward several feet. During these collapses, the upper deck and lower deck expansion joints north of Bent 104 separated. The longitudinal girders in the lower deck support span fractured and the lower deck support span hinged downward, northward from the lower Bent Cap. The upper and lower deck support spans collapsed to a level lower than the upper and lower deck support spans, with the lower deck overhang span resting on the ground.

At this location, the upper deck overhang span sloped sharply downward to the south and was at approximately the same level as the north end of the lower deck support span, which hinged sharply downward, northward from the lower Bent Cap, forming a wall at the south end of the upper deck overhang span. The upper deck sloped generally downward toward the south from Bent 107 through the overhang portion of Span 104. The overhang span also sloped westward at its southern end.

As the upper deck collapsed at Bent 106, the expansion joint north of Bent 106 separated. The support portion of the span came to rest on the lower deck at a higher elevation than the overhang

portion of the span. Based on the Cavalier's position in relation to the 300SX, it was most likely entering Span 109, at Bent 110, approximately five (5) seconds after the structure's strong motion began.

The Cavalier rode Span 109 down as it collapsed to the lower deck. It continued southbound in the S-4 lane and struck humps in the collapsed roadway at Bents 109, 108, and 106. During this period of time, the Cavalier was repeatedly launching and landing. As it was approaching Bent 105, it launched from the upper deck and landed on the rubble from Bent 105's west side upper deck support column, and from the west barrier railing in Span 105. The Cavalier came to a stop on the rubble approximately three feet from ground level.

The Cavalier was located on this rubble in a nose down attitude, but generally headed southwest, approximately 148 feet south of 32nd Street and 35 feet east of the west edge of southbound Cypress Street.

The driver was unable to open her left front door. Two Hispanic males, who were on southbound Cypress Street, were able to remove her from the vehicle through the left front window. After coming to rest, and most likely after she was helped from her vehicle, the Cavalier caught fire.

The Driver of the Cavalier sustained injury to her left eye, lacerations and abrasions on her legs, contusions and abrasions on her face and forehead and an abrasion on the left side of her neck. She also complained of pain in the right side of her chest, her right shoulder, her back, and her abdomen. She was transported to Kaiser Hospital in Oakland for treatment of her injuries.

The Chevrolet Cavalier sustained total damage to the front, the suspension, the roof and the left side. The front two-thirds of the vehicle was destroyed by fire. It was subsequently towed from the scene.

V-49

Just prior to the earthquake, a 30 year-old female was driving a gray 1986 Honda Accord southbound on I-880 in an unknown lane at approximately 55 mph. The Accord was equipped with lap/shoulder harness type restraints, and she was wearing her's.

As the structure's strong motion began, the Accord was traversing Span 117. The driver related that she suddenly lost control of her vehicle and it swerved two lanes to the left. She indicated that she applied her vehicle's brakes, and then saw the roadway open up.

Approximately four (4) seconds after the structure's strong motion began, the upper deck support columns at Bent 104 failed and the upper deck collapsed at Bent 104. The upper deck collapse at Bent 104 initiated northward and southward progressing upper deck collapses from Bent 104. Immediately following the upper deck collapse at Bent 104, and as the northward progressing upper deck collapses were occurring, there was a partial collapse of the lower deck at Bent 104, a complete collapse of the lower deck at Bent 105, and a partial collapse of the lower deck at Bent 106. The northward progressing collapses occurred as the east side upper deck support columns at Bents 105 through 111 failed, followed immediately by the failure of their respective west side upper

deck support columns. At Bent 112, the upper cap on the east side of the freeway and the west side upper deck support column failed simultaneously. As the upper deck collapsed at Bent 112, the expansion joint north of Bent 112 separated. As the support span collapsed, the joint's cable restrainers exerted force on the overhang span. As a result of the force applied by the cable restrainers, and the unsupported weight of the support span, the overhang span's longitudinal girders fractured just south of Bent 113. The overhang portion of Span 112 collapsed onto the lower deck. The upper deck at Bent 113 remained standing.

Approximately six (6) seconds after the structure's strong motion began, the northward progressing upper deck collapse had reached Span 112. At this moment, the Accord was traversing Span 112 at approximately 34 mph. Bent 112 was collapsing and the Accord launched from the overhang span, which was at a slightly higher elevation than the collapsing support span. The Accord struck the exposed north face of the support span's diaphragm with its front bumper and front wheels.

At impact, the Accord experienced an approximate 15 mph velocity loss, and then slid south in the S-2 lane an additional 30 feet. It came to rest facing south in the S-2 lane approximately 15 feet south of Bent 112, approximately eight (8) seconds after the structure's strong motion began.

The driver was subsequently removed from the Accord by fire department personnel. She sustained a depressed nasal fracture, a right orbital fracture, a mild compression fracture of the L2 lumbar vertebrae, and a mild compression fracture of the T12 thoracic vertebrae. Dr. Pat Carroll provided aid at the scene. The driver was subsequently transported to Providence Hospital in Oakland by ambulance, where she was admitted for treatment of her injuries.

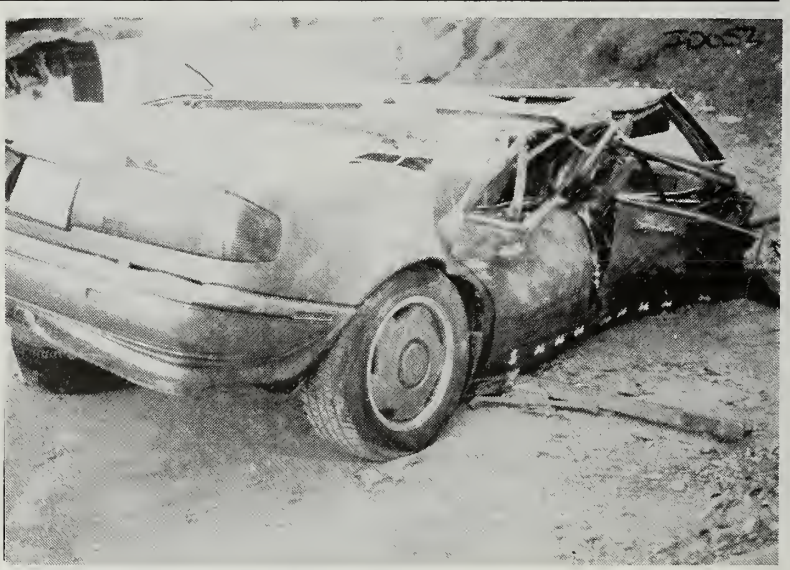
The Honda Accord sustained total damage to the front, and its undercarriage. It was subsequently removed from the freeway by a crane, and was towed from the scene.

V-60

Just prior to the earthquake, a 43 year-old female was driving a gold 1988 Pontiac SSE northbound on I-880 in the N-3 lane at approximately 55 mph. The Pontiac was equipped with lap/shoulder harness type restraints, and she was utilizing her's.

It is uncertain exactly which Span the Pontiac was traversing when the structure's strong motion began. The driver estimated that she was somewhere near 28th Street. She stated that she heard the radio announcer say that there was an earthquake under way, and she immediately felt her vehicle begin swaying wildly from side to side and bouncing up and down. She began braking and tried to steer straight ahead.

She indicated she could see the roadway swaying from side to side in a wobbly-weaving motion, and bouncing up and down as well. She also stated she saw the upper deck support columns on



the right (east) side popping out, and then a large sheet of concrete fell on her vehicle.

Approximately four (4) seconds after the structure's strong motion began, the upper deck support columns at Bent 104 failed and the upper deck collapsed.

The upper deck collapse at Bent 104 initiated northward and southward progressing upper deck collapses. Immediately following the upper deck collapse at Bent 104, and as the ensuing upper deck collapses were occurring, there was a partial collapse of the lower deck at Bent 104, a complete collapse of the lower deck at Bent 105, and a partial collapse of the lower deck at Bent 106. The northward progressing upper deck collapses occurred as the east side upper deck support columns at Bents 105 through 111 failed, followed immediately by the failure of their respective west side upper deck support columns. At Bent 112, the upper cap on the east side of the freeway and the west side upper deck support column failed simultaneously. The upper deck collapsed onto the lower deck from Bent 104 through the overhang portion of Span 112, just south of Bent 113.

Approximately four (4) seconds after the structure's strong motion began, the Pontiac was traversing Span 104, as Span 104 began to collapse. As the Pontiac reached Bent 105, it was being crushed downward by the upper deck in Span 104. As Span 104 fell onto the Pontiac, the upper cap at Bent 105 fell onto the front of the car, crushing it. The Pontiac came to rest facing north in the N-3, lane with its entire front end under the upper cap at Bent 105. Its center of mass was approximately five (5) feet south of the upper cap. The roof of the Pontiac was crushed downward to the seat tops.

The driver was pinned in her car. She was initially aided by volunteers from surrounding business. She was subsequently freed by members of the Oakland Fire Department It reportedly took four and one-half hours to extricate her from the Pontiac. She sustained a crush injury to her left knee, with associated left knee effusion, a laceration and strain of the left ankle, a contusion on the anterior chest wall, and contusions on the right forearm and the proximal right leg, an abrasion on the left shin, and a minor laceration and a periocular contusion in her right eye. She was subsequently transported to Eden Hospital in Castro Valley by ambulance, where she was admitted for treatment of her injuries.

The Pontiac sustained total damage as a result of being crushed. It was removed from the structure on November 7, 1989, at approximately 1455 hours, and was hauled from the scene.

V-74

Just prior to the earthquake, a 47 year-old male was driving a 1980 Freightliner truck tractor, pulling a 1982 Fruehauf trailer, northbound on I-880 in the N-3 lane at approximately 55 mph. The Freightliner tractor was equipped with lap belt type restraints, and the driver was utilizing his. He indicated that a yellow, 1974 VW "Bug" had just passed him in the N-3 lane.

As the structure's strong motion began, the tractor/trailer was traversing an unknown span at approximately 55 mph.

During the interview, the driver stated "Actually, it didn't occur to me that it was an earthquake until the section right in front of me fell down. Prior to that, I thought I had a blowout and I was trying to control the truck. I hit the guardrail. All this time, I noticed it didn't look right in back, in my rear view

mirror. It looked like stuff was falling. Up front, I know it was falling, because I could see it falling, one section at a time, before it got to me! I just leaned over and said good-bye because I knew I was dead!"

Approximately four (4) seconds after the structure's strong motion began, there were simultaneous upper deck collapses at Bent 104, and at Bents 89 through 92. The upper deck collapse at Bent 104 initiated a southward progressing upper deck collapse, while the upper deck collapse at Bents 89 through 92 initiated a northward progressing upper deck collapse from Bent 92.

As the upper deck collapsed at Bent 95, the expansion joint north of Bent 95 separated. As the support portion of Span 95 collapsed, the joint's cable restrainers exerted a downward force on the overhang portion of Span 95. The force exerted, coupled with the unsupported weight of the overhang span, caused the overhang span's longitudinal girders to fracture just south of Bent 96. The overhang portion of Span 95 collapsed to the lower deck at its south end. However, its north end was suspended approximately five (5) feet above the lower deck by the span's longitudinal reinforcing steel which was still attached to the upper cap at Bent 96. The upper deck support columns at Bent 96 were damaged, but did not fail. The upper deck support columns at Bent 97 were damaged and the upper cap was shifted northward and eastward, but the support columns did not fail. As the upper deck failed at Bent 99, the overhang portion of Span 98 was pulled off its seat on the support portion of the span and collapsed with Bent 99. As the upper deck support columns at Bent 98 failed, the longitudinal girders in Span 97 fractured just north of Bent 97. The portion of Span 97 north of the fracture site collapsed to the lower deck with Bent 98.

Approximately five (5) seconds after the structure's strong motion began, the tractor/trailer was traversing Span 96, at a reported 20 mph. The driver laid down on the seat because it appeared that the upper deck would collapse on his vehicle. The tractor/trailer continued north in the N-4 lane and struck the right (west) barrier rail and came to a stop in Span 96. The tractor/trailer's center of mass was adjacent to the west side upper deck support columns at Bent 97. The trailer was still connected to the tractor and was aligned behind it. The trailer came to rest in the N-4 lane at Bent 97. The trailer was attached to the tractor and was straddling the N-3 and N-4 lanes, approximately 21 feet south of Bent 97.

The driver was lying across the front seat, when he heard the driver of another vehicle knocking on the right door and calling to him. The driver, who was reportedly uninjured, exited his vehicle and joined the other driver. They checked the yellow VW "Bug", which was buried under Span 97 north of their location, but they got no response from the vehicle.

An officer subsequently came by and directed them back toward West Grand Avenue. They climbed up onto the collapsed upper deck at Bent 95 and walked south to Span 81, where they climbed back onto the lower deck. They climbed down a ladder from the lower deck to the ground in the vicinity of Bent 81.

The tractor/trailer sustained moderate damage to the top and sides as a result of being struck by pieces of falling concrete and extrication from the structure. The tractor also sustained damage to the front and side as a result of the impact with the barrier rail. The tractor and its trailer were removed from the structure on November 6, 1989, at approximately 1550 hours and 1605 hours, and were towed from the scene.

V-97

Just prior to the earthquake, a 35 year-old female was driving a 1986 Dodge Colt northbound on I-880 in the N-2 lane at approximately 50 mph. The Colt was equipped with lap/shoulder harness type restraints in the left front and right front seats, and lap belt type restraints in the left rear, center rear, and right rear seats. The driver was utilizing her restraint.

A 37 year-old female passenger in the right front seat was wearing her restraint. A 31 year-old female passenger in the left rear seat was wearing her restraint. A 28 year-old female passenger in the center rear seat was not wearing her restraint. A 27 year-old female passenger in the right rear seat was wearing her restraint.

It is uncertain exactly where the Colt was when the structure's strong motion began. The driver indicated that her vehicle suddenly began swerving from side to side, like it had a flat. She began to slow and then saw the freeway coming down section by section (indicating by gesture toward her). Then a big crossbeam fell down on the front of the car. The passengers corroborated what the driver said.

Approximately four (4) seconds after the structure's strong motion began, there was a near simultaneous collapse of the upper deck on the east side of the structure at Bents 73 through 80. At approximately the same time, there was an independent failure of the west upper deck columns at Bents 72 through 71, followed immediately by the failure of their respective east side upper deck support columns. The collapse of the upper deck at Bents 72 and 71 initiated a southward progressing upper deck collapse from Bent 70. At Bent 70, the east side upper deck support column failed, followed immediately by the west side upper deck support column. As the west side upper deck support column failed, it fell eastward into the lower deck roadway.

At this moment, the Colt was traversing Span 69 at Bent 70 in the N-2 lane at an unknown speed. As the upper deck collapsed at Bent 70, the upper cap fell on the fallen upper deck support column, at its west end, and onto the front of the Colt in the N-2 lane. The upper deck in Span 69 collapsed onto the roof of the Colt. It came to rest facing north in the N-2 lane with its front end underneath the collapsed upper cap, and its center of mass was approximately seven feet south of Bent 70.

The driver and front seat passenger were pinned in the front of the Colt. The unbelted center rear passenger was thrown forward into the windshield and dash area of the vehicle. The other two rear seat passengers were able to exit the vehicle unassisted and began calling for help.

Citizen volunteers came up and attempted to aid them, but were unable to free the driver or front seat passenger. Fire department personnel subsequently extricated them from the vehicle. The rear seat passengers were taken from the structure by citizen volunteers via a ladder.

The driver sustained a primary jejunostomy anastomosis, colostomy, left clavicle fracture, left tibia and fibula fracture, a laceration to the scalp, and a right bimalleolar fracture. She was subsequently transported to Eden Hospi-

tal by ambulance, and was admitted to the hospital for treatment of her injuries.

The front seat passenger sustained a compression fracture of the L4 lumbar vertebrae, a comminuted fracture of the right tibia and fibula, and a laceration on her right forearm. She was subsequently transported to Eden Hospital by ambulance, and was admitted to the hospital for treatment of her injuries.

The left rear seat passenger sustained a fractured left clavicle and contusion to the distal left tibia and fibula. She was subsequently transported to Eden Hospital by ambulance, and was admitted to the hospital for treatment of her injuries.

The right rear passenger sustained a fractured left humerus, a fracture to the left olecranon, a fracture to the left ulna, and a laceration on her head. She was subsequently transported to Providence Hospital by ambulance, and was admitted to the hospital for treatment of her injuries.

The center rear passenger sustained a fracture of the C7 cervical vertebrae, a laceration of the frontal scalp with a depressed skull fracture, bilateral orbital hematomas, fracture of the right humerus, and external abrasions and contusions. She was unconscious at the scene and was transported to Highland Hospital by ambulance. She was admitted to the hospital on October 17, 1989, at 2010 hours. She succumbed to her injuries and her death was pronounced on October 18, 1989, at approximately 0134 hours. Alameda County Coroner's Office performed an autopsy on October 18, 1989.

The Dodge Colt sustained total damage as a result of being crushed by the collapsed upper cap at Bent 70 the upper deck in Span 69, and subsequent rescue operations. It was removed from the structure on November 3, 1989, at approximately 1455 hours, and was hauled away from the scene.

SUMMARY CLOSING

The California Highway Patrol's investigation of the Cypress Street Viaduct collapse and the failure of the San Francisco-Oakland Bay Bridge (SFOBB) took nearly seven months to complete. The report documenting the Cypress Structure collapse consists of six volumes and an Appendix, which comprise over 1700 pages of text, charts, graphs and diagrams. Nearly 500 pages of investigative material document the effect of the 1989 Loma Prieta Earthquake on the SFOBB.

The objective of these reports was to factually document the circumstances surrounding the failure of these two structures; to identify the people and property effected by the failures, to describe how each of these structures failed, and to determine what effect the failures had on the people and property on, or adjacent to, the structures when they failed.

In attaining these objectives the California Highway Patrol, in cooperation with a number of other public agencies, accomplished the following:

1. Identified 121 vehicles that were directly or indirectly involved in the earthquake caused collapse of these two structures.

2. Completed damage assessments for each of these 121 vehicles, and reconstructed their locations on their respective structure from available evidence.

3. Identified 191 drivers and passengers of the 121 vehicles known to have been involved in the earthquake caused collapse of these two structures.

4. Assessed and described the injuries suffered by each of these 191 people.

5. Investigators successfully conducted tape recorded interviews with 117 of the 148 survivors of these two disasters.

6. Identified, located, and interviewed 245 witnesses to the 1989 Loma Prieta Earthquake and its effect on these two structures.

7. Developed a complete, detailed description of the 3/4 mile long collapsed section of the Cypress Structure and the damage it sustained.

8. Reconstructed the physical evidence associated with vehicle motion on both of these structures from aerial and terrestrial photography.

9. Prepared scale diagrams depicting the post earthquake condition of each of these structures.

10. Completed an analysis using the information obtained from the interviews with the survivors of, and witnesses to, the collapse of these two structures. From this analysis, trends related to traffic flow, vehicle speeds, vehicle motion, structure motion, driver and passenger first sensations and reactions to the earthquake, and the effect of the earthquake on the vehicles and the structures were determined.

11. Determined the time from the onset of earthquake induced vehicle motion to the collapse of both structures.

12. Determined a failure sequence for each structure and developed a failure scenario describing how each of these structures fell.

13. Developed a complete description of the event for each of the 121 vehicles and 191 involved drivers and passengers. This description documents, in detail, the sequence of events occurring from just prior to the onset of the earthquake to the point where the vehicle occupants were rescued, or otherwise removed, from their vehicles.

The information collected, processed, and documented in these investigations has already played a significant roll in reducing the number of fraudulent claims filed against the State of California by parties alleging they were injured, or suffered damage, as a consequence of the collapse of these two structures.

The data collected and reported will provide engineers and scientists with the foundation information necessary to better understand how these structures responded to earthquake induced motion and why they failed. Hopefully, this information can be used by others to improve highway transportation safety.

Researchers and historians will find the information contained in these reports invaluable in documenting the complete story of the effect of the 1989 Loma Prieta Earthquake on these structures and the people using them.

Finally, it is our hope that these reports will provide a more complete perspective of the magnitude of these tragedies and their effects on the people directly or indirectly involved in them. The heroism of these individuals, each of whom suffered so much as a result of these disasters, has touched all of our hearts. These people, their family and friends, earned our respect and garnered our empathy during the preparation of these reports.

The objective of this publication was to present a brief, factual, summary of the complete reports that was suitable in content and readability for distribution to the general public.

We hope you agree that we have achieved our goal.